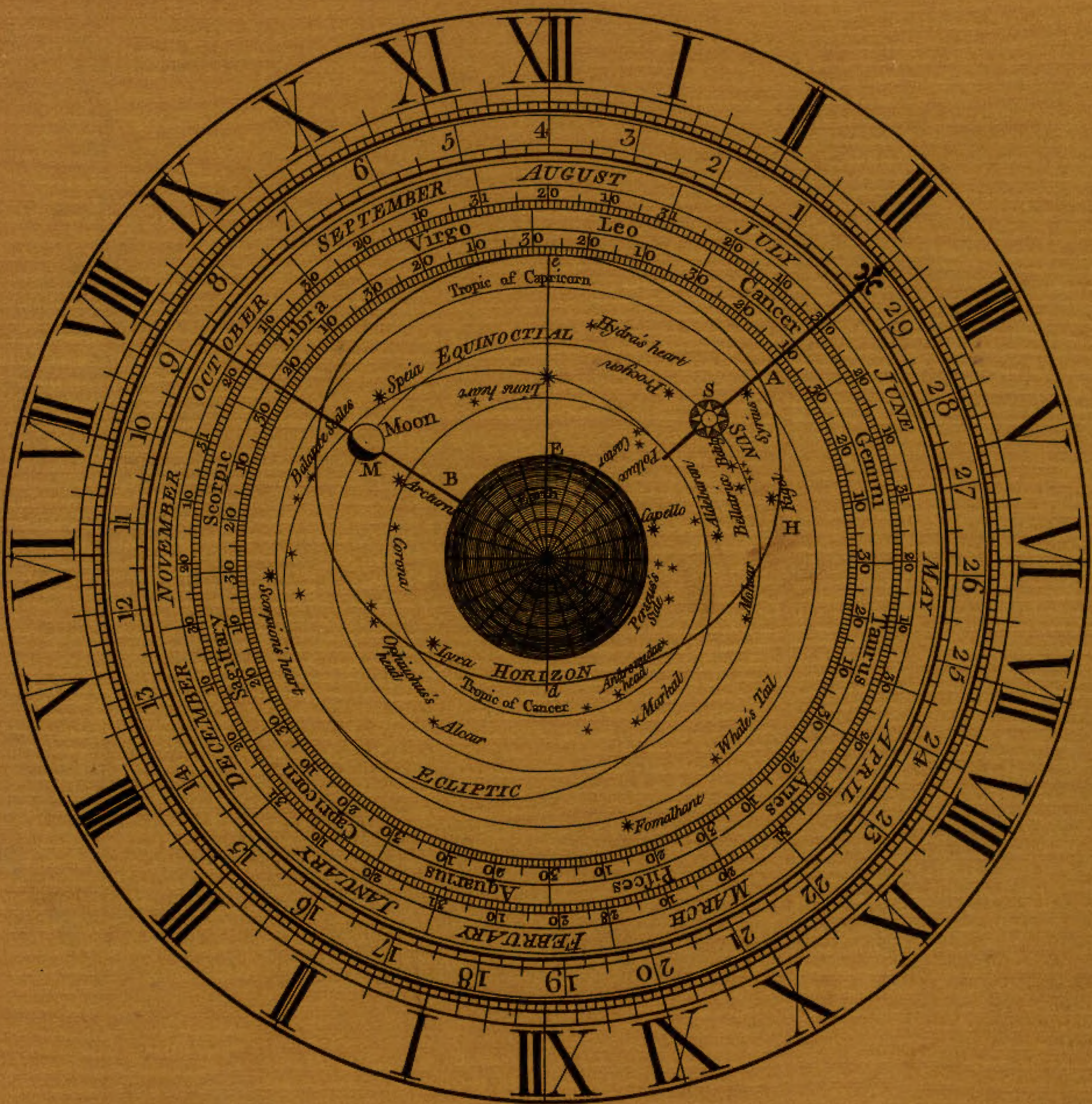
THE CLOCKWORK OF THE HEAVENS

ASPREY & COMPANY



The Clockwork of the Heavens

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The Clockwork of the Heavens

An exhibition of
astronomical clocks, watches
and allied scientific instruments
presented by
Asprey & Company
with the special help of
Harriet Wynter and the collaboration
of various museums and private collections

London
November 1973

Contents

Note on the catalogue
Descriptions of the individual items on display will be found at the end of the three main sections into which the catalogue is divided. Numbers in square brackets inserted in the text refer to the numbers of exhibits. References in the notes and captions are given in the form of a keyword which relates to the general bibliography. In describing books which are displayed only those dating before 1700 have been given full analytical entries.

The cover illustration is taken from plate 4 of James Ferguson's *Mechanical exercises*, second edition, London 1778 (see exhibit 72). The frontispiece on page 6 is a reproduction of the second title page of the 1687 German translation of Sir Matthew Hale's *The Primitive origination of mankind.*

First published in 1973 by
Asprey & Company Ltd, 165–169 New Bond Street, London W1Y 0AR

ISBN 0 904 11200 4

Printed in Great Britain by John Cordery Associates Ltd, Bushey

Foreword

In this year of the quincentenary of the birth of Copernicus, Asprey and Company decided to present an exhibition of antique astronomical clockwork.

Examples of this magnificent aspect of antiquarian horology are not nowadays to be found together in any number but are, for the most part, scattered amongst the great collections of the world. They represent the highest point of the clockmakers' art, being very often intended as masterpieces. Indeed, such astronomical clocks as those by Burgi in the Kunsthistorisches Museum, Vienna, Passement in Versailles or Fortier in the Wallace Collection, are as worthy of that term as any of the other treasures there displayed.

Surprisingly there is a paucity of literature on astronomical clocks. The amazing clock by Hilderyard now in The Royal Palace, Madrid, one of the most complicated ever constructed in England, has had no known description of it published in English apart from the maker's original manuscript of 1727 (Chronometrum Mirabile Lodiense). It is therefore hoped that this exhibition will produce fresh interest and new light on this subject.

However, it would be clearly insufficient to confine an exhibition commemorating the beginnings of a correct cosmology to the realms of horology. The astronomical clock embodies the form of other scientific instruments; the astrolabe, planisphere, planetarium and orrery. It should therefore be compared with related astronomical instruments and it is for this reason that we sought the assistance of Harriet Wynter, who very kindly agreed to form a collection especially for this exhibition. All the scientific instruments and books not otherwise acknowledged, form part of this collection.

For placing the exhibits in historical perspective as well as writing the catalogue entries for the scientific instruments, we were very pleased to secure the services of Anthony Turner. His interest in the clockwork metaphor made him all the more ideal for this task.

Obviously an exhibition of this nature could only be possible with extensive co-operation from museums and private collectors. It is chiefly to those who so nobly loaned their rare possessions that we all owe the opportunity to admire man's reconstruction of the clockwork of the Heavens.

It is my hope that this catalogue, with over fifty illustrations and sixty pages of text, will come to be regarded as a valuable book of reference by all those interested in this fascinating subject.

Finally, my fellow Directors join me in thanking Mr Sebastian Whitestone, a member of our staff, whose untiring research has made this exhibition possible.

John Asprey

Asprey & Company wish to express their appreciation to the following:

for the loan of exhibits:

Seth Atwood Esq
The Banff Museum
Herr Theodore Beyer
The Worshipful Company of Clockmakers of the City of London
Rt Hon the Earl of Cork & Orrery
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and for their valuable help and advice:

J. E. Baxter Esq
P. J. Bryden Esq
George Daniels Esq
Richard Falkiner Esq
Commander H. D. Howse, Royal Navy
Beresford Hutchinson Esq
Dr F. R. Maddison
Colonel H. Quill, O.B.E., D.S.O., M.V.O., Royal Marines
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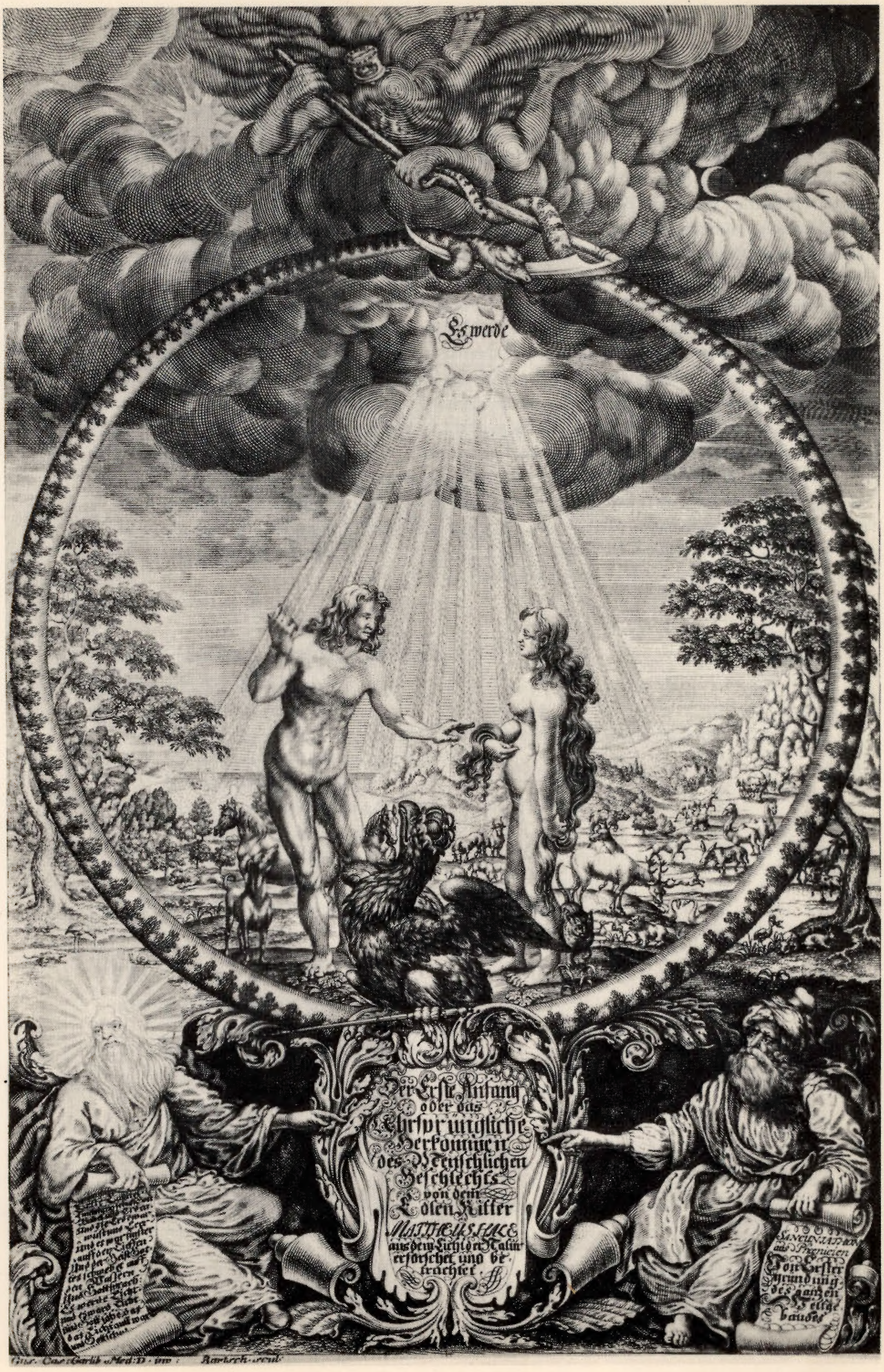
Preface

In addition to fulfilling the primary task of providing a guide to the exhibits, an attempt has been made in this catalogue to depict some aspects of the intellectual background against which the instruments shown should be set. In writing these sections, I have sought to give an outline of the development of celestial models in the period covered, and also to indicate something of the wider cultural context by illustrating some of the metaphorical uses to which they were put. For the defects which must inevitably attend such ambition I am of course alone responsible, but there remains the pleasure of thanking all those who have helped to reduce their number. In particular I owe a debt of gratitude to Professor C. I. E. Donaldson who first introduced me to the problems and fascination of the clockwork metaphor, and to Francis Maddison, who compounds learning with kindness, and whose comments on a draft of this text have much enhanced it. Without the learned enthusiasm of Jennifer Drake-Brockman and the many references that she has supplied, the catalogue would be the poorer. Charles Webster kindly read through the historical narrative in typescript and Stephen Constantine generously lightened the labours of checking the script. Catalogue entries for most of the clocks in the exhibition were written by Sebastian Whitestone, and all such entries are indicated by the initials SGW.

For help with specific problems and particular instruments, I am indebted to Mr D. J. Bryden, Miss Susan Eeles, Mr Richard Falkiner, Dr Karin Figala, Mr Richard Good, Mr W. D. Hackmann, Miss Avril Henry, Dr J. R. L. Highfield, Lt Cdr H. D. Howse, Dr R. W. Hunt, Dr J. D. North, Mr P. J. Rogers, Miss Hilary Smith, Professor P. B. Salmon, Mrs Sarah Tyacke and Miss Dione Wright.

A. J. Turner


Es werde
Der Erste Anfang
oder das
Uhrsprüngliche
Herkommen
des Menschlichen
Geschlechts
von dem
Edlen Ritter
aus dem Lichte der Natur
erforschet und be-
trachtet.

Introduction

'In the beginning God created the heaven and the earth . . .
And God said, Let there be a firmament . . .
And . . . called the firmament Heaven.
And God said, Let there be lights in the firmament of the heaven to divide the day from the night; and let them be for signs, and for seasons, and for days, and years:
And let them be for lights in the firmament of heaven to give light upon the earth: and it was so.
And God made two great lights; the greater light to rule the day, and the lesser light to rule the night: *he made* the stars also.
And God set them in the firmament of the heaven to give light upon the earth.
And to rule over the day and over the night, and to divide the light from the darkness: and God saw that it was good.'[1]

Belief in the creation of the world by a beneficient God, lies at the root of the Judaeo-Christian tradition; it is a fundamental element in Western civilisation. At all times, although the manner of expression has changed and the importance attached to it altered, some men have insisted that contemplation of the wonders of the created world, and the examination of them, was an acceptable form of worship.

The expanse of the heavens, the pattern of the skies, is the most obvious, yet also the most mysterious part of creation; it was a source of awe both for primitive races and for sophisticated nations. The rhetoric of the poet author of Job insists on the immeasurable power, the infinite creative capacity of God displayed in the natural world.

Canst thou bind the sweet influences of Pleiades,
Or loose the bands of Orion?
Canst thou bring forth the Mazzaroth [signs of the zodiac] in his season?
Or canst thou guide the Arcturus with his sons?
Knowest thou the ordinances of heaven?
Canst thou set the dominion thereof in the earth?[2]

Millenia later the informed understanding of James Ferguson considering the multiplicity of worlds could only echo this response, though in a smoother tongue.

'What an august! what an amazing conception, if human imagination can conceive it, does this give of the works of the Creator! Thousands of thousands of Suns, extending without end beyond one another, all around, and at immense distances from each other, ranged in the most beautiful order, accompanied with ten thousand times ten thousand Worlds, all in rapid motion, yet calm, regular, and harmonious, invariably keeping the paths prescribed them; and these Worlds peopled with myriads of intelligent beings, all candidates for Heaven, and capable of endless progression in perfection and felicity. If so much power, wisdom, goodness, and magnificence, is displayed in the material Creation which is but the least considerable part of the Universe, how great, how wise, how good, how adorable must HE be, who made and who guides the Whole!'[3]

If the primary purpose of studying the heavens was to glorify God, the fact that they existed was proof that they were intended for use. Astronomical study when applied to farming, to navigation or to astrology, could be severely practical. Even so it was a purer curiosity, a love of philosophical speculation which probed the physical structure and dynamic relationships of the heavenly bodies and erected theory after theory to explain them. It was in the service of these theories that the instruments displayed in the present exhibition were made. Whatever technical problems they posed mechanically, and

however their production advanced the art of clockmaker or engraver, instrument maker or mathematician, their primary purpose was to aid the student and teacher of astronomy. They were tools for investigation, demonstration aids for instruction, and, on occasion, both. Inevitably they display great variety. Some were the bare tools of scientists, others the elaborate furnishings of the rich. All however expressed the skill and learning of their day, and provoked a reverberation in its culture. It is with this interaction of astronomical models with literary and philosophical culture, that this exhibition is concerned. In particular it concentrates on the role of clockwork as a transforming force upon the ways in which men understood, and the manner in which they expressed this understanding of the cosmic harmonies.

Part 1. The Medieval World

Classical Origins

Tradition ascribes to Plato the enunciation of the basic problem for astronomy. 'For Plato, Sosiegenes says, set this problem for students of astronomy: By the assumption of what uniform and ordered motions can the apparent motions of the planets be accounted for.'[4] The theory of concentric spheres of Eudoxus of Cnidus (409–353BC), elaborated by Callipus (*fl.*330BC) and converted from a purely geometrical to a mechanical structure by Aristotle (384–322BC) was an attempt to answer this challenge. So also was the epicyclic system developed by Apollonius of Perga (*c.*262BC–?), Hipparchus (*fl.*160–126BC) and Ptolemy (*fl.*139–161AD), the semi-helio-centric system of Heraclides of Pontus (*c.*388–*c.*310BC) and the fully helio-centric system of Aristarchus of Samos (?–264BC). If the early Middle Ages was content to accept the Ptolemaic system, the problem remained and exercised the speculations of Nicolas Oresme (*c.*1320–1382) and Nicholas Cusanus (1401–1464), Copernicus (1473–1543) and Kepler (1571–1630), Descartes (1596–1650) and Newton (1642–1727).

Just as Plato's problem was the ultimate aim for theoretical astronomers, so a similar problem, to represent all these motions by a single force in a model, exercised the mechanicians. Commenting on Archimedes' planetarium, Cicero made the point clearly: 'And more especially was that invention of Archimedes to be admired, for he had so contrived that one revolution (of the machine) served somehow to produce unequal and varied movements through their different paths'.[5] The craftsman who applied geometry to produce a complex machine, which mirrored current theories, thus had a recognised role in astronomical work, as Pappus of Alexandria makes clear. 'Mechanicians are those who understand how to construct celestial globes and to represent the heavens and the course of the stars moving in circles by means of like circular movements of water.'[6]

Already in Pappus' remark, one of the fundamental pre-occupations of later instrument makers is prefigured, the desire to find in the earth some equivalent to the apparently perpetual motion of the celestial vault. This however was a technical problem. For the astronomer celestial models, whether powered or not, were required for two purposes. Firstly for demonstration, as a teaching aid which would represent immediately and visually the geometrical relationships of the planets as they appear from the earth. Such models however embody the postulations of particular theories *about* the heavens, not the *reality* of them. Secondly, such models could supply useful aids to the astronomer by reducing the amount of time required for calculating the positions of the fixed stars or the planets, the times of their appearances and similar matters. To supply these purposes various instruments were developed but always there was overlap between them.

The simple globe, a solid sphere upon which a celestial map could be drawn or painted, moulded or engraved, was well known in antiquity. Eudoxus of Cnidus is supposed to have made a globe which was later described in the astronomical poem of Aratus (*fl.*270BC). From a slightly later period, one globe, the well known Atlante Farnese, has survived and is now in the National Museum, Naples[1]. In 212BC, with the sack of Syracuse and the death of Archimedes (*c.*287–212BC) two globes by him were carried off to Rome by Claudius Marcellus (*c.*270–208BC). One of these, which was probably a solid sphere carrying a star map, was placed in the Temple of Virtue; the other, which seems to have been a form of planetarium worked either by hand or possibly by water, remained in the family of Marcellus, where it was seen, and described to Cicero by C. Sulpicius Gallus (*fl.*170–164BC). Cicero's description reveals something of its performance, but nothing of its structure.

'This species of globe, indeed, in which the sun and moon were made to revolve, and five of those stars, which have been called travellers, and as it were wanderers, [the planets] could not possibly be exhibited on that solid globe [i.e. that by Archimedes placed in the Temple of Virtue]. . . . For, when Gallus set this globe in motion, the moon succeeded the sun by as many turns of the brass wheel of the machine as days in the heavens, and so that globe represented in the heavens the same eclipse of the sun, when the moon arrived at a certain point, as the shadow of the earth did when the sun shone from the opposite region.'[7]

Archimedes' moving sphere was held in high regard in antiquity, the philosopher Posidonius (*fl.* 150–130BC) for example making a copy of it,[8] and it has been suggested that knowledge of it filtering into China may have been the stimulus which provoked the remarkable series of mechanical (water-driven) celestial globes and armillary spheres which stem from the early device of Chang Heng (*c.* 130AD) and came to fulfilment in the astronomical clock tower of Su Sung, described by him in a text of 1090AD.[9] Whether this was so or not, interest in such devices continued in the Hellenistic world particularly at Alexandria with the work of Hero, and with the invention of the anaphoric clock and the astrolabe.

The mathematical technique of mapping a sphere onto a flat surface, by means of a stereographic projection from the celestial pole onto the plane of the horizon, may have been known to Hipparchus[10] and was certainly known to Ptolemy. Both the anaphoric clock[11] and the astrolabe employed this technique to provide a model of the heavens, combining two stereographic projections to do so. One of these projections represented the celestial sphere with its stars, ecliptic and tropics; the other showed the lines of altitude and azimuth (angular distance along the horizon), as they would be for an observer at a given latitude. In the astrolabe, an open work metal star map is rotated by hand *over* a plate engraved with the lines of altitude and azimuth. In the anaphoric clock, a disc engraved with the star map is rotated by water power *behind* a fixed grill representing the lines of altitude and azimuth.[12] [2] Although there is no evidence of the use of gearing in the anaphoric clock, or of the depiction of any of the planets except the sun, the anaphoric clock is of the first importance as the predecessor of the astrolabe, and as the origin of later celestial models. Moreover as Price(1) has pointed out, it is 'the first clock dial, setting a standard for "clockwise" rotation, and leaving its mark on the rotating dial and stationary pointer found on the earliest time-keeping clocks before the change was made to a fixed dial and moving hand'.

If the sphere of Archimedes and the anaphoric clock illustrate efforts made in Hellenistic antiquity to develop automatic celestial models, as against the static globes, the astrolabe represents the development of a manually operated model primarily designed to shorten astronomical calculations. An early form of analogue computer, it is possible from the scales engraved on it to determine immediately the positions of fixed stars in relation to the horizon, the position of sun, moon and planets in relation to the fixed stars, and much other data of a similar kind. It could also be used for time-finding. The recovery from the sea-bed near the island of Antikythera in 1901 of a complex geared machine, probably dating from 65BC $\pm$ 10 years, illustrates further that from approximately the same period even more sophisticated astronomical calculating models were being developed. According to Price, this device was 'an astronomical computer for sidereal, solar, lunar and possibly also planetary phenomena'.[13] It is significant for its use of gearing, and for its strong relation to later instruments in the tradition of geared astronomical calculating models, which was inherited and developed by the Middle Ages.

Islam and the West

The mathematical technology of the ancient world was primarily transmitted to the West through Islam. Although some ancient learning was directly retained in the West after the break up of the Roman Empire, it was limited and fragmentary. To Western scholars, the inheritors of the Latin tradition in which philosophical and scientific speculations had played little part, the highly developed skills of Hellenistic technology were largely lost, as was their vehicle, the Greek language. Even so, there were some survivals. One Byzantine astrolabe and a small number of sundials exist. Further West also traces of Greek techniques are found and Dr J. D. North has recently demonstrated that certain celestial planispheres in 9th century manuscripts include stereographic projections.

While some Greek learning remained in the West, it flourished in the East. Faced with the ferocious religious and political disputes of Byzantium, many scholars trained in the School of Alexandria, which by the 6th century had been entirely converted to Christianity, had turned towards the expanding and responsive races of the Middle East – to Syria and to Persia. In 489AD the emperor Zeno closed the Nestorian school at Edessa, thus causing an exodus of scholars to Persia. In 529AD Justinian closed the neo-Platonic academy at Athens, and more scholars moved to the East. The learning they carried was eagerly received, and a large scale movement of translation made the contents of their Greek mss available in Syrian, Hebrew, Pahlavi and Arabic. During the reign of the seventh ʿAbbâssid Caliph al-Ma'mûn (786–833), himself an astronomer, the first Arabic translation of the key astronomical text Ptolemy's *Mathematike syntaxis* (the Almagest) was produced, being revised at the end of the 9th century by Thâbit b. Qurra (826/7–901). The ʿAbbâssid caliphate was particularly favourable to scientific and cultural development, erecting institutional and patronage structures for further research. Under their influence a new scientific culture grew up. 'Bagdad', it has been said, 'was the true successor to Alexandria, with the additional feature that Alexandrian science was there coupled with the Persian and Indian scientific tradition, and was splendidly enhanced over a long period – especially in the ninth and tenth centuries – by fresh scientific study and observation.'[14]

In the development of scientific instruments, the ninth and tenth centuries indeed saw many advances. In China, a form of water 'escapement' devised in the early 8th century by the Tantric monk I-Hsing was used to control the mechanism of a series of armillary astronomical models which were developed during this period.[15] In Islam, more directly in the Greek tradition, new forms of computational instruments had been devised. A work by al-Bîrûnî of *c.* 1000AD describes a special gear train for showing the revolutions of sun and moon at their relative rates and for showing the phases of the moon. According to Price this device, which could be applied to an astrolabe, is closely related to the Antikythera instrument, as well as showing in the lunar phase diagram a feature identical in form and structure with that found in later clocks.[16] One surviving Islamic astrolabe, of 1221/2 (AH618), by Muhammad b. Abî Bakr b. Muhammad ar-Râshîdî al-Ibarî [?al-Abirî] al-Isfahânî, [4-6] embodies this device.[17]

Although the astrolabe enabled many long calculations to be avoided, the computing of planetary positions, even with the assistance of tables, could easily take 15 or 20 minutes, with the constant possibility of minor errors creeping in. If several planetary positions needed to be known, as for example when casting a horoscope, the amount of work involved was considerable. It was this labour that the Equatorium was designed to lessen. While a device described by Proclus (*c.*450AD) in the *Hypotyposis astronomicarum positionum* may represent early attempts to develop such an instrument, the earliest general planetary equatorium is usually taken to be that of Abulcacim Abnacahm (Abû-l-Qâsim Asbagh b. Muhammad Ibn as-Samh of Granada, *c.*1025). A description of this device is preserved in the thirteenth century Castilian *Libros del saber de astronomía* of Alfonso X of Castile.[3]

This device was simplified shortly afterwards by Abû Ishâq Ibrâhîm b. Yahyâ an-Naqqâsh or Ibn az-Zarqâlî (Azarquiel, *c.*1029–1087).[18] No Islamic examples of these instruments have survived, but it seems unlikely that none were made. Certainly the tradition of astronomical models was not neglected for in 1232 a fine example was presented to the Emperor Frederick II (1194–1250).

> 'In the same year, the Saladin of Egypt sent by his ambassadors as a gift to the Emperor Frederic a valuable machine of wonderful construction worth more than five thousand ducats. For it appeared to resemble internally a celestial globe in which figures of the sun, moon, and other planets formed with the greatest skill moved, being impelled by weights and wheels, so that performing their course in certain and fixed intervals they pointed out the hour night and day with infallible certainty; also the twelve signs of the zodiac with certain appropriate characters, moved with the firmament, contained within themselves the course of the planets.'[19]

While these developments were taking place in Islam, there was little that the Christian West could offer to compare. In the tenth century, Gerbert (*ante* 950–1003, later Pope Sylvester II) described the making of a sphere to Remi, a monk of Trier, as 'a most difficult piece of work . . . do not shudder that it will require a year'.[20] One of the leading teachers of his day, and a strong advocate of the study of arithmetic and astronomy, Gerbert was acquainted with water-clocks and sundials, and had also designed some form of celestial demonstration model, although whether it was water-driven, manually operated or static is not clear.[21] Gerbert in his time however was isolated, and it was only gradually that Greek knowledge seeped back into the West through the transmission of Arabic mss and instruments from the Maghrib (i.e. Moslem Spain and North Africa) into the rest of Western Europe. The influx of Arabic learning carrying with it much that derived from the ancient world, can be seen beginning in the late ninth and tenth centuries, a notable centre in the later part of the period being the translation school of the Benedictine monastery of Santa María de Ripoll in the Pyrenees. Translation came to a peak in the eleventh and twelfth centuries. By then Western scholars such as Adelard of Bath (*fl.*1110–1142) and Gerard of Cremona (*c.*1114–1187), who published the first Latin version of the *Amalgest* in 1175, were travelling to Spain to absorb the new learning and disseminate it further West. Equally important as carriers and translators of the new texts were the Jewish communities in Spain and Southern France. Mainly centred on Toledo, the Hebrew communities were particularly well equipped linguistically to make Latin versions of Arabic works available.[22] As the translations which they produced were gradually disseminated, so the traditions of Greek scientific technology, adapted and developed by the Arab commentators, became available once more to Western scholars. As they did so, the early pre-occupations of the classical world were once more seen in the West.

Invention of the Mechanical Clock

The position held by the celestial models transmitted from Islam to the West, as a necessary part of astronomical study, was in part traditional, and in part caused by the success of the Ptolemaic system. Once Ptolemy's theories had become generally accepted, it was natural that those topics which had chiefly concerned him should become the central pre-occupation of later scholars. Thus medieval and early modern astronomy tended to concentrate on planetary theory. The influence of this on instrument making has already been seen in the case of the equatorium, an instrument specifically designed to ease calculations relating to planetary positions, and which in its very construction embodied the geometrical structures of Ptolemaic theory. A further result sprang from the accuracy of the theory. Given that it worked, instrument makers attempted to produce models which would show the planets following the rules prescribed for them; tracing out in the

microcosm the same paths that they were now assumed to follow in the macrocosm. This however raised a formidable technical problem. The heavenly spheres moved of themselves; how could a model be made to follow them?

As Pappus' statement that mechanicians know how to make celestial models move in circles 'by means of like circular movements of water' makes clear,[23] the problems of driving astronomical models were being discussed at Alexandria from an early date. What was required was a source of power which could be regulated to drive a celestial model in exact accordance with the heavens. In the effort to accomplish this various possibilities were explored, albeit somewhat haphazardly, involving the use of water, sand, mercury, magnetism and ultimately weights and gearing. With the details of these developments, or the problem of how the mechanical escapement was eventually produced, we are not here concerned. What is important is that the object of these efforts was to produce, 'a wheel which will make one complete revolution for every one of the equinoctial circle'.[24] If such a wheel could once be perfected, it might then be applied for different purposes as needed. Robert Anglicus comments on its value as a device for reckoning up the unequal hours. Equally well, however, it could be applied to drive other models such as astrolabes or equatoria, globes or armillary spheres. A diagram in the *Libros del Saber*[9] depicts a weight-driven drum with a mercury controller similar to some Islamic perpetual motion devices. This is shown driving round the *rete* of an astrolabe. In the case of the astrarium of Giovanni de' Dondi (1364) the mechanical regulator which eventually emerged from these experiments is used to drive a series of equatoria.[25] Other attempts tried to make the model into its own source of power. In his *Epistle on the Magnet*, (1269, but in part known to Roger Bacon before 1250) Petrus Peregrinus (Pierre de Maricourt, *fl.* 1250–70) described the properties of the lodestone and suggests that it has a mysterious sympathy with the heavens. If therefore a *terella*, a sphere perfectly uniform in every part, is carefully made, and mounted in an armillary sphere with its axis directed along the polar axis, it should move in sympathy with the heavens. With such an instrument he says, 'you will be relieved from every kind of clock *(horologium)*, for by it you will be able to know the Ascendant at whatever hour you will, and all other dispositions of the heavens which Astrologers seek after'.[26]

From the uses to which it was intended a regulating device should be put, it is possible to see how one important stimulus for its development was the sense that it could be valuable for the technical study of astronomy. What other needs it might meet, for ringing bells, timing carillons, controlling automata or other devices, are difficult to assess, but certainly not negligible. Exactly when the mechanical escapement was invented is not known, nor by whom, or even where. If it seems unlikely to have been produced much before 1250, it was almost certainly available by 1300. In the following century it came into widespread use, but two applications of it stand out. They are those to the great clock built by Richard of Wallingford in the abbey of St Albans, and the astrarium built by Giovanni de' Dondi at Padua.

Wallingford and de' Dondi

Richard of Wallingford (?1292–1336) was the orphan son of a smith of Wallingford who, after studying at Gloucester College, Oxford, for six years, entered the monastery of St Albans. Three years later he was sent back to Oxford where he remained for a further nine years. Oxford at this time was one of the leading schools of astronomical and mathematical study in Europe, and here Richard carried out important work on trigonometry, besides designing a number of new instruments, notably the albion and the rectangulus, a form of torquetum. In 1327, Richard was elected abbot of St Albans in succession to Hugh de Evesdon, and it was probably not long after that he began construction of his

clock. Work on it continued throughout his abbacy, the clock being left unfinished at his death from leprosy in 1336. It was later completed during the abbacy of Thomas de la Mare (1349–1396) by Laurentius de Stokes, *horologiarius*, and another monk, William Walsham.[27]

In about 1540, the antiquary John Leland (?1506–1552) gave the clock a brief description in his itinerary of Britain: 'one may look at the course of the sun and the moon or the fixed stars, or again one may regard the rise and fall of the tide, or the lines with their almost infinite variety of figures and indications'.[28] In fact Wallingford's clock, besides striking the hour, was an elaborate astronomical model with an astrolabe dial and mechanisms for showing the motions of sun, moon and planets, besides demonstrating lunar eclipses.

Giovanni de' Dondi (1318–1389) was born in Chioggia, the son of the municipal physician, Jacopo de' Dondi (*c.*1290–1329), who had himself designed and supervised the building of the astronomical clock in the Piazza dei Signori at Padua. After working in Padua for many years, where, trained as a physician himself, de' Dondi was in 1359 appointed a member of all four of the university faculties of medicine, astrology, philosophy and logic, he moved to Pavia where he received the patronage of Gian Galeazzo Visconti. He died at Milan on 22nd June 1389.

According to Philippe de Maisières (1312–1405) who himself knew de' Dondi he 'with his own hand forged the said clock, all of brass and copper, without assistance from any other person, and did nothing else for sixteen years'. The 'clock' thus produced was in effect a mechanised equatorium, and de' Dondi himself implies this in the *Tractatus astrarii* when he reveals that he 'derived the first notion of this project and invention from the subtle and ingenious idea propounded by Campanus de Novara in his construction of equatoria, which he taught in his *Theorica planetarum* . . .'. De' Dondi's astrarium is thus a self-moving version of the complicated models which had been produced to embody the arguments of Ptolemaic planetary astronomy which itself was a theoretical model of the heavenly movements. An instrument of the kind that Robertus Anglicus and Petrus Peregrinus had desired, it became the marvel of its age. 'I do not believe', Giovanni Manzini wrote to de' Dondi in July 1388, 'that there was such competency in art at that time [i.e. of Posidonius], nor was there such mastery of skill as is shown in this. I do not believe that any of posterity can make it or excel it, since in the passing of time we do not see such sublime growth of genius . . . '[29]

The Impact of the Clock

The rapid spread throughout Europe of a machine which was at once expensive and unreliable, attests to the fascination that the clock exerted over the imagination from the moment of its invention. The most simple bell-sounding movement was an object for wonder and delight. Froissart, for example, declared:

> 'For the clock, if well we ponder, is
> An instrument most fine and notable,
> And pleasant is, besides, and serviceable;
> For night and day the hours it lets us know,
> Through the subtlety that it possesses,
> Even in the absence of the sun:'[30]

The clock could indeed perform a task that no other medieval instrument could, and as such had a role to play both in everyday life and in the more learned world of astronomy. The two, however, were closely linked. In 1473, Bartolomeo Manfredi argued that the astronomical dials of the public clock at Mantua showed 'the proper time for phlebotomy, for surgery, for making dresses, for tilling the soil, for undertaking journeys and for other

things very useful in this world'.[31] The mechanical equatoria of de' Dondi's astrarium were equally useful to the astronomer, and were more marvellous. According to Philippe de Maizieres, probably because of his great knowledge in astronomical matters, de' Dondi's family name was generally forgotten, 'and he is called master John of the Clocks'. From distant places moreover, '... great astronomers came to admire his work ...'[32] What was so admirable in the astrarium was that it showed the order which underlies complexity. 'Using his keen mind, he built a perfect machine, where the intricate mass of the orbs and planets is clearly and distinctly known to be moved in an orderly manner, so that it seems to be a divine rather than a human work.'[33] In building a model of the cosmos, God's handiwork, de' Dondi proved that rational man partakes of God's nature. He also showed that the universe might be thought of as a machine which had been constructed. In the *Livre du ciel*, Nicolas Oresme, made this point explicitly.

> 'In the absence of any resistance similar to the balance which regulates the movement of clock-hands, the speed of the spheres would not stop increasing so that to keep the stars' rate, the divine clockmaker (l'horologier divin) had to calculate a complicated system of actions and reactions.'[34]

If by the mid-fourteenth century, clockwork was already providing philosophers with a mechanical analogy for the universe, and God had made his appearance as the divine clockmaker, the reason for this was that astronomical clocks represented mechanical versions of mathematical models of the heavens. These mathematical models, as has already been noted, set out to give an account of the observed complexity of the heavens in terms of simple elementary principles; to display the essential harmony and regularity of the arrangement of the stars and planets. This regularity could now be represented by a celestial model; it therefore offered an image of harmony. The arrangement of gears, weights, ropes and spindles which made up the mechanism driving the model however was itself a complex of many parts the action of which was caused by a single motion. Thus the clockwork part, as well as the visual model, supplied an image of harmony, and was used by religious writers to represent the relationship of the soul with God. By other writers, notably Froissart, it was used to symbolise human love.

For a public clock to keep reasonably accurate time, it required a permanent attendant.[35] If the soul and body of man were to function in harmony they also required a supervisor, a role which was supplied by Wisdom, personified as a woman. For this relationship the clock supplied an apt image, indeed, it played a part in it as Dante makes clear:

> 'Then as the horologe, that calleth us, what hour the spouse of God riseth to sing her matins to her spouse that he may love her,
> Wherein one part drawing and thrusting other, giveth a chiming sound of so sweet note, that the well ordered spirit with love swelleth;
> So did I see the glorious wheel revolve and render voice to voice in harmony and sweetness that may not be known except where joy maketh itself eternal.'[36]

Later Dante finds the wheels 'in harmony of clockwork so turn that the first, to whoso noteth it, seemeth still and the last to fly', similar to the different strains, fast and slow, of the blessed spirits singing praises to God.

In most of the metaphors derived from clocks, what is emphasised most strongly is the ordered complexity resulting from the simple initial impulses produced by the wise contrivance of God and carefully maintained. It was in this way that man's body and soul should act together, responding to the force of the weight of the love of God. Used like this, the image extrapolated back from the small man-made mechanical celestial model – the microcosm – to imply the mechanical basis of God's whole universe – the macrocosm – in which it was man's place to play only a *part*. The means by which the great world

worked were not known, but man was granted a sufficiency of insight into God's mechanical skills to copy it in little and therefore to know that regular principles existed which guaranteed the perfect adaptation of each part to the functioning of the divine whole. It followed therefore that man as a rational and spiritual being had no alternative but to follow the precepts of divine law. If he did not, the perfect harmony of the creation would be upset. It was how to do this that Wisdom taught, and it was in a popular mystical work on this theme, the *Horologium sapientiae*, that the clock metaphor reached its most comprehensive expression.

The German mystic, Heinrich Suso (1300–1366) wrote the *Horologium sapientiae* in the period 1333–1341. It became one of the most popular works of the later Middle Ages, over two hundred manuscript copies of the original Latin version being known. In 1389 it was translated into French by an anonymous Franciscan *maître de théologie* and numerous other versions of it exist.[37] The purpose of the work which takes the form of a dialogue between the Lady Wisdom and a disciple (who represents Suso himself) was to summon souls back to the eternal truths, just as a clock sounding the hours regularly through the day calls men to divine office. It is Wisdom that keeps the clock, and causes men to heed the message rung out upon its bells that, 'God, who is before the centuries and time, has made man in material shape'.[38]

Wisdom shows to the disciple a clock 'of very beautiful and very noble form of which the wheels were excellent and the bells sounded sweetly, and by its varied and subtle design, every human heart marvelled and exulted in looking at it'.[39] In this image, as in those used by Dante, it is the variety and subtlety of the clock which is foremost, while the sweet sound of its bells symbolises the surge of joy experienced by the heart moving towards God when, like the excellent wheels and varied parts of the clock, soul and body are in concord. Such images long continued in use. A century and a half later for example, Timothy Bright (*c.*1551–1615) used the idea in a closely similar manner to illustrate how the soul 'by one simple faculty performeth so many and divers actions'.[40]

> 'We see it euident in automaticall instruments, as clockes, watches, and larums, how one right and straight motion, through the aptnes of the first wheele, not only causeth circular motion in the same, but in diuers others also: and not only so, but distinct in pace, and time of motion: some wheeles passing swifter than other some, by diverse rases: nowe to these deuises, some other instrument added, as hammer and bell, not only another right motion springeth thereof, as the stroke of the hammer, but sound also oft repeated, and deliuered at certaine times by equall pauses, and that either larum or houres according as the partes of the clocke are framed. To these if yet moreover a directory hand be added, this first, & simple & right motion by weight or straine, shall seme not only to be author of deliberate sound and to counterfet voice, but also to point with the finger as much as it hath declared by sound. Besides these we see yet a third motion with reciprocation in the ballance of the clock. So many actions diuerse in kinde rise from one simple first motion, by reason of variety of ioynts in one engine. If to these you adde what wit can deuise, you may find all the motion of heaven with his planets counterfetted, in a small modil, with distinction of time and season, as in the course of the heauenly bodies.'

Part 1: Exhibits

1 THE ATLANTE FARNESE GLOBE

Photograph.

A first century AD marble copy of a globe which probably dates from the third century BC. It shows forty-two constellation figures and is supported by Atlas resting on one knee.
See Stevenson, p.15.
The National Museum, Naples.

2 PRINCIPLE OF THE ANAPHORIC CLOCK

Photograph.

Part of the dial of an anaphoric clock was found at Salzburg. Originally the bronze dial was about 1700mm in diameter, and was turned by the action of a moving float.
See Price (2), p.91.

3 LIBROS DEL SABER DE ASTRONOMIA DEL REY D. ALFONSO X DE CASTILLA

Edited by D. Manuel Rico y Sinobas, five vols, large folio. Madrid 1863–67.

A series of astronomical works edited by the king's order in 1276–77. The work, which was intended to be so complete that other books would be unnecessary, consists of a mixture of new translations from Arabic, revised versions of existing translations, treatises which are largely original and introductions and prefaces by the translators and the king himself.

A work of the first importance in the history of astronomy and of horology, the making of the translations in this and other works ordered by Alfonso was instrumental in establishing a technical and scientific vocabulary in Spanish.
See Sarton, vol.ii, pp.835–7, 839–42.
Loaned by A. J. Turner, Esq.

4 PERSIAN ASTROLABE WITH GEARED CALENDAR MOVEMENT

Photograph. Signed by Muhammad b. Abî Bakr of Isfahân in 1221/22AD.

Face, showing the *rete* with two lugs for sighting since the use of an alidade on the back was precluded by the calendar, which was probably operated by turning the horse (wedge) and pin.
See Mayer, p.59; Bedini & Maddison, pp.9–10; Price (1), pp.98–100.
Museum of the History of Science, Oxford. IC no. 5.

5 PERSIAN ASTROLABE WITH GEARED CALENDAR MOVEMENT

Photograph. Signed by Muhammad b. Abî Bakr of Isfahân in 1221/22AD.

Back showing calendar. The circular opening shows a lunar phase diagram which should be compared with those found on other European horological instruments and the dials of long case clocks. The rectangular opening gives the age of the moon and so the date according to a lunar calendar. The circular scale at the bottom of the instrument supplies a zodiacal calendar within which are two concentric rings which, as they rotate, show the relative positions of sun and moon (i.e. in conjunction, opposition, etc) and the position of the sun in the zodiac. The inscription in the centre is the maker's signature.
See Mayer, p.59; Bedini & Maddison, pp.9–10; Price (1), pp.98–100.
Museum of the History of Science, Oxford. IC no. 5.

6 PERSIAN ASTROLABE WITH GEARED CALENDAR MOVEMENT

Photograph. Signed by Muhammad b. Abî Bakr of Isfahân in 1221/22AD.

Inside of backplate showing the gear train similar to that described by al-Bîrûnî *c.*1000AD.
See Mayer, p.59; For the gear train count, Bedini & Maddison, p.10, and Price (1), p.99.
Museum of the History of Science, Oxford. IC no. 5.

7 INDO-PERSIAN ASTROLABE, *c.1600*

Mater of silver; plates of brass. Signed on the back below the shadow square 'Made by the most humble of servants 'Isà b. Allah-dâd the royal astrolabist of Lahore'. Diameter 262mm.

Rete for between fifty and sixty named stars. Five plates, for latitudes 18°/29°, 27°/32°, 37°/40°; 0°/combined projection for latitudes 24° and 30°; a tablet of ecliptical co-ordinates; tablet of horizons. In addition to the usual lines of unequal hours, drawn below the horizon line, lines for Babylonian and Italian hours are drawn on many of the plates. A gazetteer of latitude and longitude for various places is engraved on the interior of the mater.

The back is engraved around the edge of the upper semi-circle with a degree scale. In the upper left quadrant is a sine-graph; in the upper right quadrant an unequal hour diagram. In the centre of the lower semi-circle is a shadow square surrounded by scales for cotangents, and a scale for correlating the signs of the zodiac with the twenty-eight astrological mansions of the moon. In modern green velvet lined, red tooled morocco case. IC no. 68.
See Gunther (1), p.167, no. 68.

8 PERSIAN QIBLA INDICATOR, *early eighteenth century*

Brass. Signed on upper surface 'Made by 'Abd al-A'[imm]a'? Diameter 66mm.

Circular box with hinged lid, containing a compass of which the needle is missing. Above this is a cut-away plate engraved with a semi-circular scale of degrees. Tables for the *inhiraff* and *jiha* of various towns are engraved on the lid, and on the outer surface of the base.

An adaptation of the compass dial, this instrument enables the azimuth of the *qibla* (direction of Mecca) to be determined, and so the time and direction for prayer.

9 MERCURY CLOCK OF ISAAC B. SID, *1276/77*

From the *Libros del saber de astronomia del D. Rey Alfonso X.*

The clock consists of an astrolabe dial, rotated as in an anaphoric clock, which is fitted with thirty leaf-shaped gear teeth. This is driven by a pinion of six leaves mounted on the horizontal axle attached to a weight-driven drum containing a mercury 'escapement'. In the centre of the drum are twelve chambers, six of which are filled with mercury. As the drum revolves the mercury is supposed to trickle through the small holes in the chamber walls.
See Price (1), pp.100–101.
Loaned by A. J. Turner, Esq.

10 RICHARD OF WALLINGFORD BESIDE HIS CLOCK, *middle to late fifteenth century*

Photograph.

Miniature painting from an untitled manuscript described by Thomas Smith in his *Catalogus librorum manuscriptorum Bibliothecae Cottonianae*, Oxford 1696, p.57, as 'A Catalogue of benefactors and all those who had been received into the brotherhood of the Monastery of St. Albans, with short histories of them, and most elegant illustrations'. A list of abbots, etc, at f.46*v* was completed in 1484.
British Museum, Ms Cotton Nero D.vii, f.20*r*.

11 RECONSTRUCTION OF THE ESCAPEMENT OF RICHARD OF WALLINGFORD'S CLOCK

Messrs Thwaites & Reed Ltd, after a reconstruction by John North.

This form of escapement has previously been known only through the writings of Leonardo da Vinci and other contemporary Italian authors. It is now thought however to be perhaps the earliest form of the verge and foliot escapement.
Loaned by Messrs Thwaites & Reed Ltd.

12 RICHARD OF WALLINGFORD'S CLOCK

Artist's impression by David Hazard from a reconstruction by John North.

13 THE MERTON EQUATORIUM, *c.1350*

Photograph.

One of the very few medieval equatoria still surviving, the instrument is engraved on the back of an astrolabe which is possibly the *astrolabium magnus* left to Merton College in 1372 by Simon Bredon. Consisting of a single plate of brass engraved for the latitude of Oxford (52° 6′), the y-type gothic *rete* depicts thirty-two stars and is engraved with a rule with fiducial edge. Sighting is carried out by the pinnules set on either side of the suspension ring, since there is no alidade. The equatorium engraved on the back consists of a set of nesting graduated circles each representing a planet within an outer zodiac circle. The design is similar to that of the instrument devised by Azarqiel, although the pinnules can only be paralleled in the *Tractatus Albionis* of Richard of Wallingford. A second plate which should go with the instrument and was probably attached by a string to the small lug at the bottom, has been lost. Within one of the two inner circles is a table showing corrections to be made for precession in the century 1350–1450.
For a full description and discussion, *see* Gunther, vol.ii, pp.208–10; Price (3), pp.128–30.
Merton College, Oxford. IC no. 297.

14 THE ASTRARIUM OF GIOVANNI DE' DONDI, *1348–46*

Reconstruction by Messrs Thwaites & Reed Ltd.

Giovanni de' Dondi's astrarium was designed to display the motions of the five known planets according to Ptolemaic planetary theory. The dial of Mercury, with that of the moon and Saturn, is the most complicated, in that three motions have to be represented. In solving the considerable problems this posed, de' Dondi employed elliptical wheels, and what has been claimed as the first known example of an internally cut wheel.
For a detailed description of the technical construction of the astrarium, *see* Lloyd (2), pp.9–24.
Loaned by Th. Beyer, Esq.

15 IOANNIS / DE SACROBVSTO / LIBELLUS DE / SPHAERA. / ACCESSIT EIUSDEM AVTORIS COMPUTUS EC- / *clesiasticus, Et alia quaedem in stu- / diosorum gratiam edita.* / CVM PRAEFATIONE / Philippi Melanthonis. / Impressum Vitebergae / apud Vitum / Creutzer. / ANNO, / M.D.XLV. / [John of Holywood, Little book of the sphere, to which is added the ecclesiastical reckoner of the same author, and certain other works set forth for the benefit of students with a preface by Philip Melancthon.]

Foolscap octavo, coloured device of sphere on title page, woodcuts and diagrams in text, two with movable volvelles, and one with movable pointer, two folding tables.

Contemporary ms annotations (mainly in the earlier part of the text). Ownership inscriptions of Leonhard Baldussius, Halle 1568; Andreas Raselius, 18 July 1578; Cornelius of Regensburg, 1632; Bookplate of the Royal Meteorological Society, Symons bequest, 1900.

Nineteenth century half vellum and marbled boards.

Collation: A–R^8. Second title page on I^{3}r: LIBELLVS / IOANNIS DE SACRO / BVSTO, DE ANNI / RATIONE, SEV / ut vocatur uulgo / COMPVTVS / Ecclesiasticus. / [three dots] / CVM PRAEFATI- / one Philippi Me- / lanthonis. / 1545 / [device] / [Little book on the reckoning of the year, or as it is commonly called the ecclesiastical calculator, with a preface by Philip Melancthon.] Houzeau & Lancaster, no. 1653; Zinner, no. 1881.

Ioannes de Sacrobosco (*fl.c.*1230) is one of the more mysterious figures of the thirteenth century, little being known about his life beyond the fact that he taught in Paris where he seems to have composed and used his treatise. Of his surviving works, the most important are all elementary textbooks of mathematics or astronomy.

His treatise of the sphere is described by Thorndike (2) as the 'clearest, most elementary, and most used textbook in astronomy and cosmography from the thirteenth to the seventeenth century'. Combining traditional western astronomical knowledge, which ultimately stemmed from Macrobius and Ptolemy, with the fresh ideas derived from the twelfth century Latin translations of Arabic writers, particularly Alfraganus, the work perhaps dates from early in the thirteenth century, before 1220. Manuscript copies of the treatise on the sphere were numerous in the Middle Ages, and it was translated into Hebrew by the Provençal scholar Solomon Abigdar in 1399. The advent of printing redoubled the number of available copies.

The first (Ferrara) edition of 1472, was only the second published work on astronomy. The edition by Philip Melancthon (1497–1560) was first published at Wittenberg in 1531.

The treatise *de Anni Ratione* dealing with problems of the calendar, was translated into Icelandic before the end of the thirteenth century, and was also popular. The present edition by Melancthon (his preface dated 1538) is the first printed edition; it was several times reprinted. *See* Thorndike (2); Sarton, ii, pp.617–19.

Provenance: The Royal Meteorological Society, 1900–1973. Andreas Rasel (*c.*1563–6 January 1602), born at Halmbach near Amberg in the Upper Palatinate, was the son of a Lutheran preacher. He studied at Wittenberg University under Melancthon himself, who was responsible for the Latinising of his name as Raselius. In 1584 he was appointed Cantor and teacher at the 'Gymnasium' in Regensburg, of which town he published a chronicle history, as well as several volumes of musical compositions, mainly settings of Lutheran psalms and chorales. In 1600 he was appointed *Hofkapellmeister* at Heidelberg.

See Groves', Dictionary of music and musicians, fifth edition, 8 vols., London, 1954, vii, p.50.

16 MINIATURE ARMILLARY SPHERE, *sixteenth century*

Gilt brass, with traces of vermilion colouring in the stamping. Diameter 55mm.

The rings for the arctic and antarctic circles, the equator and tropics of Cancer and Capricorn are named in Latin as are the solstitial and equinoctial colures. The ecliptic/zodiac circle is divided on both sides in degrees for each sign. Not signed; two minor repairs; mounted on a later brass stand; probably removed from an astronomical clock or other large instrument.

17 SACROBOSCO

Engraving on paper from André Thevet, *Les Vraies pourtraits et vies des hommes illustres Grecz, Latins et payens, recueillez de leurs tableaux, livres, medailles antiques et modernes*, two vols, folio, Paris 1584, vol.ii, f.545*r*.

André Thevet (1502–1590) travelled widely through the Middle East, and made an unsuccessful voyage to Brazil in order to gather materials for his cosmographic works. Appointed historiographer and cosmographer to Charles IX he claimed that he brought engravers from the Low Countries specially to engrave the portraits for the *Vie des hommes illustres*. The portrait of Sacrobosco he states derives from one in the library of Robert Guaguin but it is unlikely to be an authentic likeness. The armillary sphere shown is unusual in having two handles.

See O'Donaghue, vol.ii, p.551; *N.B.G.*, vol.xlv, p.127. Loaned by A. J. Turner, Esq.

18 THE CLOCK AS A SYMBOL OF THE WELL-ORDERED LIFE

Miniature illustrating the *Epître d'Othéa* of Christine de Pisan, 1450.

The clock placed centrally in the landscape is being adjusted by Temperance, shown as a goddess, so that, with all its parts working harmoniously together, it will perform accurately in the way intended by its maker. Seated below, and watching this demonstration of the place of moderation in human affairs, are four 'aspects' of the cardinal virtue.

From a manuscript made for Sir John Fastolf and probably written in England. Fastolf's motto 'Me fault fayre' and the date 1450 are found on f.93.

See Pächt & Alexander, no. 695; Tuve.

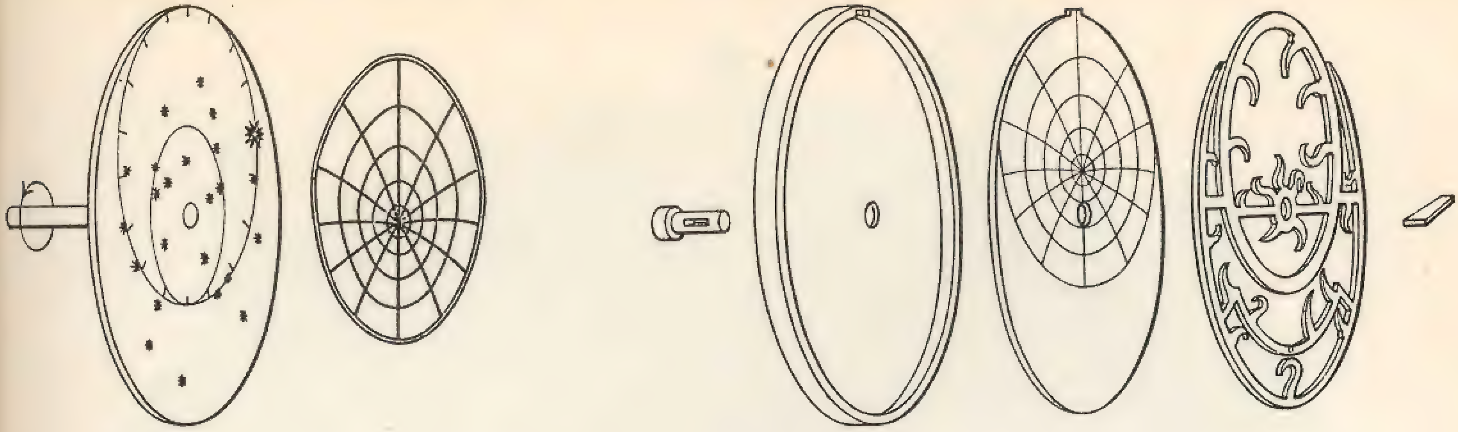
Bodleian Library, Oxford. Ms Laud misc. 570, f.28*v*.

19 TEMPERANCE SHOWN WITH HER SYMBOLS, THE CLOCK AND A BRIDLE

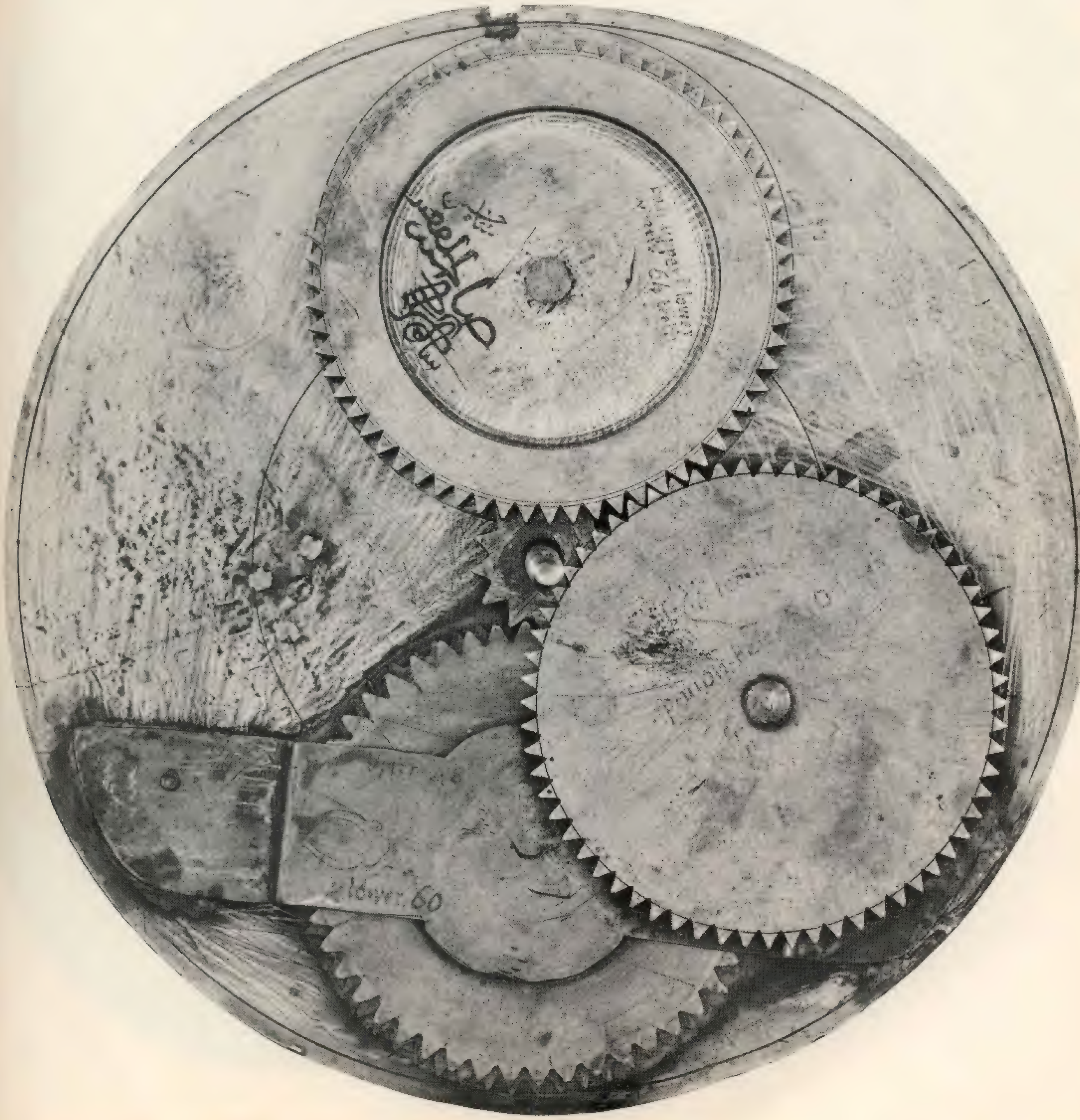
Carving on wood. ?French/Flemish. Sixteenth century.

The depiction of Temperance with a clock, often unusually large or of considerable complexity, was one of the innovations of the 'new iconography' of the four virtues which is found in fifteenth century manuscript illuminations. The first of the two treatises in Ms Laud misc. 570 (*supra* 19) is among the earliest of these at present known. The programme of this iconography attempted to give a visual exposition of the characteristics of the four cardinal virtues in the Ciceronian-Macrobian tradition (Justice, Prudence, Temperance and Fortitude) and to show the ways in which these manifested themselves, by means of appropriate symbols. Although the origins of this allegorical imagery are obscure, it may be associated with the circle of the court of Burgundy, and perhaps dates from the middle or late fourteenth century.

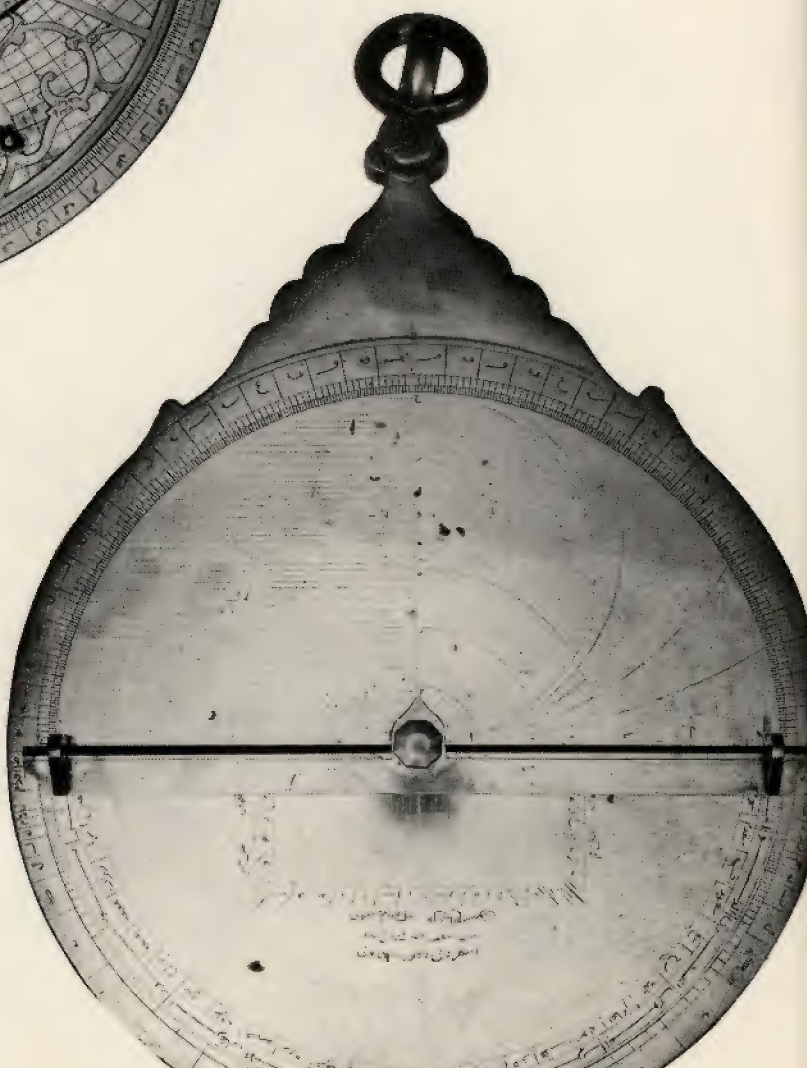
See Tuve.



2. Principle of the anaphoric clock. Left - rotating star-map and fixed grill of anaphoric clock (reconstruction); right–mater, plate and star-map (rete) of an astrolabe, showing the same arrangement reversed.



6. Persian astrolabe with geared calendar movement



7. Indo-Persian astrolabe, *c.*1600

13. The Merton equatorium, *c.*1350

16. Miniature armillary sphere, sixteenth century

19. Temperance shown with her symbols

Part 2. Renaissance Transformations

New Heavens and New Earth

Medieval astronomy, like that which followed it, was primarily directed towards theology. It sought to give a satisfactory predictive account of the movements of the heavenly bodies in terms of a physical theory of the universe which exhibited at every point the perfect contrivance of the world by God the creator. To think of the resulting cosmological picture in terms of a machine, especially one which itself mirrored the celestial motions, was quite natural. Guillaume de Sallust, Sieur du Bartas (1544–1590) for example used a common analogy

‘. . . like as also in a clock well tended,
Just counterpoise justly thereon suspended,
Makes the great wheel go round, and that anon
Turns with its turning many a meaner one,
The trembling watch and th'iron maul that chimes
The entire day in twice twelve equal times,
So the grand heaven in four and twenty hours,
Surveying all this various house of ours,
With his quick motion all the spheres doth move
Whose radiant glances gild the world above,
And drives them everyday, which swiftness strange is,
From Gange to Tagus and from Tay to Ganges.’[41]

Neither for du Bartas nor for his English translator was there any reason for doubt about the divine order and arrangement of the cosmos. For them, man had only to wonder at it and to use it; those who felt doubts were quickly dismissed.

‘These clerks who think – think how absurd a jest! –
That neither heavens nor stars do turn at all,
Nor dance about this great, round, earthy ball,
But th'earth itself, this massy globe of ours
Turns round about once every twice twelve hours.’[42]

Yet the confidence felt by a du Bartas was displaced. Whatever the exact details of the mechanical construction of the heavens about which there had always been debate, the revival of interest in astronomical computation and planetary theory, partly stimulated by projected reform of the calendar[25], led to a recognition of the incompatibility between Ptolemaic planetary theory and the physical ideas of the universe derived from Aristotle and his followers. It was a consciousness of this incompatibility, combining with a recognition of the increasingly evident deficiencies of Ptolemy's theory, which led to new investigations and the reinterpretations of part of the *Amalgest* by men such as Oresme, Cusanus and Copernicus.[43] That Copernicus' theory in modified form should have eventually established itself as the basis of a new orthodoxy is a matter of historical accident that does not concern us here. What does matter is that the structure of the universe continued to be thought about in a mechanical way, and that instrument makers continued to make models that would embody the new theoretical constructions. Traditional forms and theories were of course slow to die, and new astronomical theories were extremely slow to gain general popular assent. None the less the sixteenth and seventeenth centuries display some interesting technical and metaphorical developments.

‘God’, claimed Thomas Powell, ‘framed the world by Geometry (as we may say) that is, with wonderful Art; he did all things in Number, Weight and Measure. *Aristotle* calls him . . . The great Engineer of the World, that tacked this rare *Systeme* of heaven

and earth together, tackt the Center to the Sphears, and made the whole Frame to move in a wonderful order from its first creation to this day . . .'[44] If however the entire fabric of the world be taken as a single machine, it is 'a greater wonder then all other wonders in the world'. It is 'a kinde of an *Automaton* or Engine that moves of it self, much like a great Clocke with wheels and poyzes, and counterpoyzes, that is alwaies in motion, though no bodie moves it'. Just as the great world, the macrocosm, is an automaton, so also to Powell is the little world of man – the microcosm – and that of animals.[45] All things are machines designed by God; by imitating their principles Powell believes man can himself make further machines. To do so would be godly work.

With the overt mechanism of Powell, we are brought face to face with the optimistic, operative approach to nature typical of many sections of sixteenth and seventeenth century society. By imitating God's creations, man himself could control nature and surpass its powers. The working models of the heavens, which Powell acclaimed as the acme of art, were the warrant and sign of man's technical capabilities. The self-moving, celestial perpetual motion machine which Cornelius Drebbel presented to James I, and which Powell described, underlined the point.[46]

Yet if the conception of the universe as a vast clockwork machine was now pressed into service to justify a conception of man as an active agent in creation, controlling and transforming the natural world for his own purposes, the older uses of the metaphor continued. In 1609, Cristóbal Gonçalez saw man, like the bell of a clock, as the reason for and glory of a harmonious universe.

> 'If we look at a clock we shall find therein a whole host of springs, wheels, chains, pins, cogs and weights, all of which move and function so that a bell, placed in the topmost part of the mechanism, rings and strikes the hours. But if this bell were not to ring, nor to keep time, we should say, and rightly, that the whole of this cunning mechanism was rendered useless. After this fashion we may philosophize about the whole fabric of the world, which is like a clock, set by God on those mighty wheels (circles) of the heavens, some of which move slowly, others quickly, some turn one way, others another, and all in time with the *primum mobile*. And having created the elements and all the other creatures, which are the chains and weights of the clock, and having set man, the most perfect of creatures, like the bell atop all of them, so that like a well-regulated clock he should give perpetual praise and glory to God . . . '[47]

In a touching English epitaph of the same period the division of the soul and body at death was likened to the period of time which a clock spends undergoing repair.

> 'As when a curious clock is out of frame
> a workman takes in peeces small the same
> and mending what amisse is to be found
> the same reioynes and makes it trewe and sound
> so god this ladie into two parts tooke
> too soon her soule her mortall corse forsooke
> But by his might att length her bodie found
> shall rise reioyned unto her soule now cround
> Till then they rest in earth and heaven sundred
> att which conioyned all such as live then wondred.'[48]

At the end of the seventeenth century, Francis Lee (1661–1719) mystic and reformer, was still to find the traditional ideas of the *Horologium sapientiae* fruitful. In 1697 he wrote a small treatise *Horologium Christianum* in which each part of the clock was used to symbolise some aspect of the christian life. The keeper of the clock was Christ himself, while its pendulum, for example, represented the reciprocating love of the intellectual faculty and God; it was the very pulse of divine life in man.[49] Other adaptations of the metaphor

however while equally traditional were less spiritual. Jean Froissart, as noted earlier, had employed the clock to supply an elaborate symbol for human love, a use which seventeenth century writers considerably extended. Sir John Suckling, for example, employed the image to charming effect in a short lyric published in 1632.[50]

That none beguiled be by times quick flowing,
Lovers have in their hearts a clock still going;
For though Time be nimble, his motions
are quicker
and thicker
where Love has his notions:

Hope is the main spring on which moves desire,
And these do the lese wheels, fear, joy inspire;
The ballance is thought, evermore
clicking
and striking
and ne're giving oer.

Occasion's the hand which still's moving round,
Till by it the Critical hour may be found,
And when that falls out, it will strike
kisses,
strange blisses,
and what you best like.

Philosophical Doubt

While the clockwork metaphor became used with increasing frequency during the seventeenth century, reflecting the steady increase in popularity of clocks and watches themselves, it also underwent an important development at the hands of the natural philosophers. Plato's problem had been to account for the diverse celestial movements by single uniform ones. Subsequent cosmological theories can all be seen as attempts to answer this problem in abstract geometrical terms. The physical truth of such hypotheses however was not insisted upon, and it was so that Copernicus' followers (whatever may have been Copernicus' own intentions) attempted to present his theories. In the Christian world however a single divine creator meant that there could be only *one* truth about the universe. In the thirteenth century, with the recovery of most of Aristotle's works, a large scale synthesis had been erected which combined the geometric planetary theory of Ptolemy with the physical views about the universe held by Aristotle's followers. One result of this was that future theories would have to take account of both the observed motions of the heavenly bodies, and the assumed physical structure of the universe. However useful a purely geometrical theory of planetary motion might be (if accurate) for technical astronomy, it was a wider cosmology which tied heaven and earth together in a single satisfying system which was ultimately required, and for which in Western Europe there was a deep psychological need.

It cannot be too strongly emphasised that the aim of seventeenth century natural philosophy was to establish the single indubitable truth about the universe. By what mechanism did the great cosmic clock operate was the problem it set itself to solve. While belief in a single God remained strong, there could only be one true explanation. That man could find. The difficulty however was to know how it might be recognised.

'For Nature is set a going by the most *subtil* and *hidden* Instruments; which it may be have nothing *obvious* which resembles them. Hence judging by visible appearances,

we are discouraged by supposed *Impossibilities* which to *Nature* are none, but within her Sphear of Action. And therefore what shews only the outside, and sensible structure of Nature; is not likely to help us in finding out the *Magnalia*. 'Twere next to impossible for one, who never saw the inward wheels and motions, to make a watch upon the bare view of the *Circle* of *hours*, and *Index*: And 'tis as difficult to trade natural operations to any practical advantage, by the sight of the *Cortex* of sensible appearances.'[51]

The pessimistic view here expressed by Joseph Glanvill (1636-1680) derived ultimately from Descartes who in the *Principles of Philosophy* used the clock metaphor to set out a probabilistic philosophy of science.

'Although I may have imagined causes capable of producing effects similar to those we see, we should not conclude for that reason that those we see are produced by these causes; for just as an industrious watchmaker may make two watches which keep time equally well and without any difference in their external appearance, yet without any similarity in the composition of their wheels, so it is certain that God works in an infinity of diverse ways [each of which enables Him to make everything appear in the world as it does, without making it possible for the human mind to know what of all these ways he has decided to use]. And I believe I shall have done enough if the causes that I have listed are such that the effects they may produce are similar to those we see in the world, without being informed whether there are other ways in which they are produced.'[52]

Descartes was highly influential, especially during the middle decades of the seventeenth century, and a similar position was adopted by the English philosopher Robert Boyle (1627–1691). It was not however a satisfying position, and by the end of the century was being challenged, especially in England. Ironically it was the same metaphor of the clock, which Descartes had used to assert his probabilism, that now served to provide an alternative.

Among the earliest critics of the probabilistic position in England was Henry Power (1623–1668), a physician working in Halifax. Power was very clear about man's duty towards God:

'Certainly this World was not made onely to be Inhabited, but Studied and Contemplated by Man; and, How few are there in the World that perform this Homage due to their Creator? Who, though he hath disclaimed all Brutal, yet still accepts of a Rational Sacrifice; 'tis a Tribute we ought to pay him for being men, for it is Reason that transpeciates our Natures, and makes us little lower than the Angels: Without the right management of this Faculty, we do not so much in our kind as Beasts do in theirs, who justly obey the prescript of their Natures, and live up to the height of that instinct that Providence hath given them.'[53]

Power was equally clear that the way to come to the truth about nature was to build models of it.

'These are the days that must lay a new Foundation of a more magnificent Philosophy, never to be overthrown: that will Empirically and Sensibly canvass the *Phaenomena* of Nature, deducing the Causes of things from such Originals in Nature, as we observe are producible by Art, and the infallible demonstration of Mechanicks: and certainly, this is the way, and no other, to build a true and permanent Philosophy: For Art being the Imitation of Nature (or, Nature at Second-Hand) it is but a sensible expression of Effects, dependent on the same (though more remote Causes;) and therefore the works of the one, must prove the most reasonable discoveries of the other. And to speak yet more close to the point, I think it is no Rhetorication to say, That all things are Artificial; for Nature it self is nothing else but the Art of God. Then,

certainly, to find the various turnings and mysterious process of this divine Art, in the management of this great Machine of the World, must needs be the proper Office of onely the Experimental and Mechanical philosopher. For the old Dogmatists and Notional Speculators, that onely gaz'd at the visible effects and last Resultances of things, understood no more of Nature, than a rude Countrey-fellow does of the Internal Fabrick of a Watch, that onely sees the Index and Horary Circle, and perchance hears the Clock and Alarum strike in it: But he that will give a satisfactory Account of those *Phaenomena*, must be an Artificer indeed, and one well skill'd in the Wheelwork and Internal Contrivance of such Automaticall Engines.'[54]

Committed to finding absolute truth, and with a less subtle mind than Descartes or Boyle, Power was unable to see the logical difficulties of his assertions, and so ignored them. His error however was that of many and his argument from the clock would be repeated by Hooke, Cowley and even John Locke. One fact helps account for Power's assertion. Unlike Descartes he had actually made a mechanical model of the heavens.[55] He knew therefore that the principles of construction could be grasped and understood. Indeed, throughout the century, clock and instrument makers had been experimenting with numerous forms of celestial model to represent the new theories. When eventually with the publication of the *Principia*, Newton seemed to reveal the last details of the clockwork heavens, it was not long before a satisfactory working model was made to represent that system in little.

Clockwork Heavens

Between the great astronomical models of the Middle Ages, derived ultimately from the traditions of Greek technology, and the products of the renaissance makers there is continuity. Wallingford's clock, as has been seen, was described by Leland and seen by many, if little understood. De' Dondi's astrarium, the later history of which has been more closely studied, retained its fame but posed problems of maintenance. Thus in 1440, and again in 1456, the instrument was repaired by Guglielmo Zelandino who has been identified with Guillelmus Zelandinus (*fl.* 1440–1494) instrument maker to King René of Sicily for whom he is said to have produced a sphere exhibiting the movements of the planets at all hours of the day and night. He was also the author of a treatise on the equatorium written in 1494.[56] According to Regiomontanus (1436–1476) who himself saw the astrarium and began to construct a copy of it, 'innumerable prelates and princes have flocked to that place (Pavia) as if they were about to see a miracle and not without cause'.[57] Possibly it was the association between Regiomontanus and the instrument maker Hans Dorn of Vienna (*d.* 1509, who himself built the remarkable celestial globe, *c.* 1480, which was later presented to the Jagellonian University at Cracow by Martin Bylica of Olkusz, 1433–1493[58]) that led to an interest in de' Dondi's instrument in late 15th century Cracow. Certainly the astrarium was well known in the fifteenth century; it remained in the castle at Pavia, though in a bad state of repair, at least until 1529/30. The Emperor Charles V saw the movement in Italy and was sufficiently impressed with it to authorise Gianello Torriano (*c.* 1500/15–1583/5) to build a copy of it.[59] The ultimate fate of both this and de' Dondi's original instruments however are not known.

The patronage of the Emperor Charles V is one link between the astrarium of de' Dondi and a comparable planetary device made between the years 1561 and 1563 by Eberhardt Baldewein [22] for Wilhelm IV, Landgrave of Hesse (1532–1592). The clock made by Baldewein was, like de' Dondi's, a mechanised equatorium. It arose from the desire of Wilhelm IV to own a clock which would show planetary positions immediately in the same way as these could be represented by moving the paper volvelles in Peter Apian's *Astronomicum Caesareum* (1540), which was dedicated to Charles V.[60] Apian's

work itself belongs to the long tradition of medieval equatoria devices, and it is interesting that volvelles of the same kind were employed by Guillelmus Zelandinus – who, as noted above, had himself probably worked on the astrarium – in his treatise of 1494.[61] Whether Wilhelm IV and Baldewein themselves had knowledge of de' Dondi's instrument or not, it is clear that their clock belonged to the same tradition. Several further instruments of this type are known from records, but only one early example has survived, this being the planetary clock now in the Bibliothèque Sainte-Geneviève, to which Oronce Fine (1494–1555) added two dials in 1553,[62] shortly after it had been removed from Metz. The rest of the instrument is of south German workmanship and appears to date from the late fifteenth century, or the early years of the sixteenth.[63]

As the tradition of mechanical equatoria continued to be developed by Renaissance makers, so also the other forms of celestial model, astrolabes, astrolabe-quadrants, globes and armillary spheres were also exploited. Mechanical celestial globes were particularly popular during the second half of the sixteenth century and early decades of the seventeenth century with wealthy patrons and were also often incorporated in the top of the planetary clocks already mentioned.[64] The root of their appeal was not simply their beauty. Poulle and Hillard have pointed out[65] how perfectly the planetary clock supplied the information needed in astrology concerning the relation of the zodiac with the twelve celestial houses, and the exact position of the planets at a specified time. Dr. Hans v. Bertele[66] has further commented on the use of the mechanical globes for this purpose. In the traditional, yet changing world of the late sixteenth century, astrology was an integral part of a single cosmology. This, it has been said, 'was a tightly-knit coherent system of aprioristic correspondencies. The study of nature and man which followed from it must be set against a background where all science, despite its compartments of psychology, medicine, botany, metallurgy and the rest, was intimately linked with the whole cosmic hierarchy'.[67] Thus if a man's body was a little world made up of the same elements which made up the natural world in which he operated, so his soul, with its triple division of vegetable, sensible and rational, paralleled the macrocosm divided into mineral, animal and spiritual parts. Such correspondencies operated at every level, in producing a celestial model man made himself like to God, he also produced a tool which enabled him to predict changes in the heavens and therefore upon himself. Technical astronomy and judicial astrology were totally inter-related [26 and 27] and the work of the clock maker was partly determined by this fact. The globes and spheres of the late renaissance were peculiarly the products of a world in which harmony and correspondence were felt to exist between its parts [21].

Yet while the fact that harmony existed was certain, that men knew how the divine creator arranged this perfection was not so sure. That the clock came to stand as a symbol of the uncertainty of knowledge has already been noted, and Evans has drawn attention to its characteristic role in the symbolism of Mannerism and some aspects of Baroque art 'as illuminating the fallibility of reason and immediate experience'.[68] It was this recognition which allowed room for re-evaluations of received systems, such as Copernicus carried out. As they occurred, so also were the characteristic models adapted to accommodate them.

Perhaps to be numbered among the earliest examples of a Copernican model is the armillary sphere by Johann Wagner of Nurnberg, now in the Germanische Nationals-museum, which, made in 1540, seems to have been converted to show the Copernican system a few years after its enunciation.[69] General acceptance of Copernicus however was extremely slow and sixteenth century models of the system are rare. From about 1600 however dates the important unsigned, geared equatorium now in the City of Liverpool Museum [28]. The maker of this instrument, while continuing to work in the traditional

manner, has adopted some Copernican ideas.[70] Another interesting early example is the globe clock made by Jobst Burgi (?1552–*c.*1620) now in the Kunst historisches Museum, Vienna, which displayed the Copernican, Ptolemaic and Tychonic systems.[71] As the seventeenth century wore on, Copernican models became slowly more popular, usually in the armillary type. In England at least, their popularity was greatly enhanced by the publications [34] of Joseph Moxon (1627–1700) who devoted one small treatise entirely to *The Use of the Copernican spheres, teaching to solve the phenomena by them as easily as in the Ptolemaic sphere* (1665). The instrument here described however was derived from those of Blaeu (see below).

In the late medieval Ptolemaic system, sun, moon, planets and stars were assumed to be rigidly attached to a series of transparent crystal spheres which revolved inside each other, carrying the planets round with them. For a visual demonstration model therefore, the armillary sphere was clearly the most convenient. In the Copernican system by contrast although the planetary orbits were still concentric in the ellipse, they were also thought of as being more or less co-planar. For such a system the sphere was not so convenient. A new form of model was required.

Zdenek Horsky[72] has pointed out that the dials of many medieval monumental clocks, such as those at Padua, Frescia, Rostock, Hampton Court and Wells can in fact be considered as planetaria, while Crommelin has drawn attention to the planetary dial in the second Strasbourg clock of 1573. Following the geared tellurium of Adriaan Anthonisz, *c.*1600, the celebrated Dutch map and globe maker Willem Janszoon Blaeu (1571–1638) made several Copernican instruments, some of which he described in 1634. In 1645 Antonius Maria Schyrle von Rheita (1597–1660) devised a water-powered Copernican machine. Andreas Busch's globe of 1653 is a well known armillary type model surviving at Gottorp Castle, while Olaus Roemer (1644–1740) and Christiaan Huygens both devised instruments primarily designed to enable planetary positions to be found quickly.[73] Huygens' instrument was made by the clock maker Solomon Coster, and still survives. In England John Flamsteed's patron Sir Jonas Moore (1617–1679) owned a clockwork-driven celestial model although of what kind is not entirely clear.[74] In general however, astronomical models may have been comparatively rare in England. Discussing them Derham mentions as famous examples only those of Archimedes, William of Zeland, Janellus Torrianus and the planetary clock of Samuel Watson purchased by Queen Mary in 1690. 'It may be questioned he adds whether those Machines were common or not; I believe they were rarities then [in antiquity], as well as Mr. Watson's and others are accounted now.'[75] Samuel Watson produced a number of planetary clocks [31][76] but it was not until the end of the century that a simpler model which could be copied and repeated was produced by Tompion and Graham.

At about the same time that John Rowley was experimenting with flattened forms of armillary sphere made of wire[77] while making instruments for the Earl of Orrery, Tompion and Graham developed a hand powered, geared model showing the sun, moon and earth system [44]. It was this or a very similar instrument which in 1712 Rowley saw and copied for the Earl of Orrery, naming it after him [45], as Richard Steele explained, 'That Honest man [Rowley] calls his machine the *Orrery* in gratitude to the nobleman of that title; for whose use and by whose generosity and encouragement he began and accomplished the undertaking'.[78]

20 GERMAN PLANETARY CLOCK, *late fifteenth/early sixteenth century*
Photograph.

The planetary clock from the Bibliothèque de Sainte Geneviève, to which Oronce Fine added two dials, the astrolabe dial and the hour dial, in 1553. Belonging to the same tradition of planetary clocks as those of Richard of Wallingford, the de' Dondi astrarium and the 'globe clock' of Eberhardt Baldewein, it is the oldest known surviving example of this type.
See Hillard & Poulle.

21 SOUTH GERMAN TABLE CLOCK, *c.1560–70*
Gilt metal case with cast and gilded bronze frieze; movement of brass and steel. Stamped with initials 'MTA' on backplate (twice). Diameter 230mm; height 89mm.

The dial has a zodiac ring, astrolabe *rete*, plate and hands which (with the possible exception of the minute hand) are all later replacements. Originally it probably had a plate carrying diagrams for the unequal hours and for Italian hours. There would probably have been a sun hand, a moon hand and perhaps a minute hand. The subdivision of the twenty-four-hour chapter ring is presumably for decoration only as its total of 268 has no significance. The movement has a verge escapement, fusee with chain, and had hour striking with an alarum set from the base. There was also a day of the week dial on the base.

The case carries a frieze portraying Orpheus playing a viola gamba, with Eurydice and Cerberus at the entrance to Hades, and with various animals between trees and rocks. Possibly this frieze is a product of the workshops of the noted goldsmith of Nuremberg, Wenzel Jamnitzer. A probable iconological association between the Orpheus scenes, which are known on a group of nine clocks, and the clocks themselves has been suggested by Neumann. He argues that the scenes are pictorial allegories of musical harmony which was closely linked with Pythagorean theories of cosmic harmony and the music of the spheres. *[SGW]*
See Coole & Neumann.
Wernher Collection, Luton Hoo.

22 MECHANICAL CELESTIAL GLOBE, *1575*
Base of fire gilt bronze, meridian of steel damascened with silver and gold; globe silvered and decorated with gold and various enamels; movement of iron. Not signed, but by Eberhardt Baldewein; frame cast by Wolff Mayern, Nuremburg. Overall height 556mm; diameter of globe 350mm.

The globe is in two sections joined along the line of the ecliptic which is marked with the signs of the zodiac, and contains a narrow ring carrying the sun's effigy. The fixed horizon ring carries a date pointer which is read against the adjacent revolving calendar ring inscribed with the days of the month, saints' days, and months of the year. This ring contains an aperture at the side for the day of the week. Fixed to the meridian ring is a twice twelve hour chapter ring with single hour hand. This is at the north pole of the instrument, while at the south pole is a small dial for adjustment of the hog's bristle regulator, and an arbor extended from the movement to transmit the drive to the calendar ring and day of the week disc. The globe may be adjusted for latitude and the top finial contains a compass.

The following information may be obtained from the globe:

1. Mean time
2. Sidereal time
3. Times of sunrise and sunset daily
4. Approximate solar noon
5. Amplitude of the sun
6. Rising, setting and culmination of stars shown
7. Right ascension and declination of stars
8. Altitude and azimuth of stars for any hour
9. Right ascension and declination of planets or comets whose position has been plotted on the globe.

The movement is wound through the centre of the hour hand which shows sidereal time, revolving with the globe once in a sidereal day. The mean time conversion train is driven by a hollow arbor concentric with the sidereal arbor and produces a retardation of approximately ·00363′ of a revolution per sidereal day. This achieved by the gearing $4/18 \times 6/367$.

The ecliptic ring is driven by the same mechanism, the gearing being $72/16 \times 487/6 = 365{\cdot}25$ days.

The calendar ring revolves once in 366 days and therefore has to be adjusted at the end of February each year except in the bissextile.

Made for Wilhelm IV, Landgrave of Hesse, and completed in 1575. [SGW]

See Drach.

From a private collection.

23 CALENDARIVM / ROMANVM MA- / gnum, Caesare maiestati dicatum, D. Ioanne / Stoeffler iustingensi Mathematico / authore. /
[The great Roman calendar dedicated to the Emperor. Johan Stoeffler of Justingen, mathematician, author.] Jakob Koebel, Oppenheim 1518.

Folio, 138 leaves, woodcut illustrations in text and numerous ornamental initials, historiated woodcut title-border; printed in red and black throughout; contemporary blind-stamped, pigskin binding over wooden boards. The make up of the book, of which the signatures are not continuously numbered, is as follows: $\star^6$, $\star\star^8$, ff. 1–74, A^6, B^8, C^4, D^6, E^8, cols. 1–64, illustrations of instruments 4.

Johannes Stoeffler (1452–1531) who corresponded with Melancthon and Reuchlin, was ordered to publish his views on the calendar by the Lateran Council (1512–17), in need of advice on its reform following the thirty year gap after the death of Regiomontanus in 1476. This he did in the first part of the present work. The four instruments depicted at the end of the work are a device for finding the position of the moon in relation to the zodiac; an horological quadrant; a Regiomontanus dial; and an azimuth dial for unequal hours.

Loaned by M. Nicolas Landau.

24 ELVCIDATIO / FABRICAE VSVSQ; / ASTROLABII, IOANNE / STOFLERINO IVSTIN- / gensi authori: / Cum diligente recognitione, una cum Sche- / matum negotio accomodatorum, exa- / ctissima expressione. / *Adiectus est index rerum & verbo* [–] / *rum copiosissimus.* / [device] / PARISIIS, / Apud IACOBVM QUESNEL, via Iacobaea, sub / signa Columbarum / [demi-rule] / M.DC.XIX. /
[Explanation of the making and use of the astrolabe by Johan Stoeffler of Justingen, with a diligent re-investigation, with great pains taken over a suitable style, and most precisely expressed. To which is added a most full index of words and things.]

Octavo, pp. 8, 173; printer's device of armillary sphere on title page, numerous illustrations in text, two folding tables. Contemporary vellum binding with remains of tags for fastening. Ownership inscription on title page, 'p Augustiniani conu par. In suburbijs sti Germanus' with shelf marks. A library stamp, presumably of this institution, has been cut away without affecting the text.

Collation: a^8, A–X^8, Y^6 (Y^6 missing, ? blank). Folding tables between K^1v & K^2r; O^3v & O^4r.

The treatise on the astrolabe by Johannes Stoeffler attained a very great popularity in the sixteenth and seventeenth centuries after its first publication in 1512/13 and was frequently reprinted. The treatise supplied in traditional manner a full description of the making and use of an astrolabe, together with numerous examples and was an excellent text for teaching. It is perhaps the best of the early illustrated printed descriptions of the instrument.

See N.B.G., xl. cols. 513–5; A.D.B., xxxvi, pp. 317–8; Gunther, ii, pp. 229–30.

25 *PRIMVS* / TRACTATVS / *BREVIS ET VTILIS* / DE TEMPORE, CON- / *scriptus in gratiam stu- / diosorum, per* / IOHANNEM GARCAE- / um Iuniorem, Pastorem Ecclesiae *DEI* / in nova arce Brenni. / [device] / *VITTEBERGAE* / *EXCVDEBAT IOHANNES* / CRATO. / [demi-rule] / ANNO M.D.LXIII. / [A first, short and useful treatise concerning time, written for the benefit of students by John Garcaens the younger, pastor of the church of God in New Brandenburg.]

Octavo, pp.16+303, device of armillary sphere on title page. Rebound, lacks folding tables.
Collation: a–b⁸, A–T⁸.
Zinner, no. 2306.
Bound with:
SECVNDVS / TRACTATVS / DE TEMPORE, SIVE DE / ORTV ET OCCASV STELLA- / rum fixarum ad quodlibet tem- / poris momentum. / AVTORE / *IOHANNE GARCAEO IVNIO-* / re, *Pastore Ecclesiae* DEI *in noua / arce Brennonis.* / [device] / Epigram, Ps xxxiii / [demi-rule] / ANNO M.D.LXV. /
[A Second treatise concerning time, or concerning the rise and setting of the fixed stars at any moment of time whatever.]
Collation: A–O^8, P^4. Folding tables between I^7v & I^8r; N^1v & N^2r; P^3v & P^4r (? lacks four); pp.8+215.
Zinner, no. 2366.
Bound with:
TERTIVS / *TRACTATVS* / DE VSV GLOBI ASTRI- / FERI, COLLECTVS / STVDIO / *IOHANNIS GARCAEI* / *IVNIORIS.* / [device] / Epigram Ps xix / *VITEBERGAE* / [demi-rule] / ANNO M.D.L.XV /
[A Third treatise, concerning the use of the celestial globe assembled by the zeal of John Garcaens the younger.]
Collation: aa–hh^8 (lacks hh^8–? blank); pp.8+106+1.
Zinner, no. 2367.

John Garcaens the younger (1530–1575) was born at Wittenberg, where he studied mathematics under Caspar Peucer, a pupil of Sacrobosco's editor Philip Melancthon (see no. 15 *supra*) within whose circle of students he may be numbered. Appointed Professor at Greisswald in 1561, Garcaens wrote a number of Latin works on astronomy, astrology and meteorology besides the present related work on time. The combination of his interests in astronomy, theology and astrology illustrates how integrally related these subjects were thought to be in Renaissance cosmology. At the same time, they stand as examples of the later sixteenth century attempt to establish astrology on a firmer empirical basis by inductive methods.
See A.D.B., viii, pp.370–1; Thorndike, vi, pp.99, 102–5.

26 GERMAN PLANETARY VOLVELLES, *c.1574–75*
27 Printed paper with three rotatable 'dials', mounted in pine frame.

Volvelles for the sun and mercury, probably taken from the set of eight published by Leonhardt Thurneisser, *Des Menschen (der sonnen, des mons . . .) circkel und lauff*, for the years 1575–1580.

Leonhardt Thurneisser zum Thurn (1531–1596) was born at Basle, where trained as a silversmith, he also acquired much skill in botany. Leaving Basle at an early age, he wandered through Europe practising as a soldier, merchant, engineer, physician, astrologer and diviner. As a physician Thurneisser was an early and ardent disciple of the alchemically based methods of Paracelsus, a fact reflected in the symbolism employed in his works.

The two instruments shown here were designed to ease such astronomical calculations as were necessary in practices of astrology, alchemy and Paracelsian medicine. The inscription in the cartouche (on that for the sun, no. 26) discusses the exact position of the sun on the 6th of the Ides of March (i.e. 10th March), according to five different chronological systems. The outer narrow rim of the volvelle itself is marked 'primum mobile habitatio Dei altissimmi potentissimmi cum sanctis electis suis qui est omnium rerum'. (The primum mobile, the habitation of the all-powerful God most high who is lord of all, with his elect spirits.) The second ring contains the names of the more important angels, and the third (wider) ring contains a calendar scale with various named festivals. Inside this is a divided ring containing the names of various countries with their latitudes, and following this a ring containing thirty-two wind-

names. The last ring of the base contains a zodiac scale with twenty-eight named stars (? of Paracelsian significance). Engraved in the central circle (only visible in no. 27) are an *aspectarium* and a diagram of the celestial houses.

Rotating over and within these scales are three 'dials'. The lowest of these shows pictorial representations of various star constellations; the second with what appears to be a circular tree diagram, partly marked in Latin and partly in German; the third carries further star constellations. Above these rotates an ecliptic circle, a dragon representing the nodes, while in the centre of this is a figure of Hermes shown with specifically Paracelsian attributes. The Aramaic inscription surrounding this figure consists of the three words for wisdom, knowledge and Jehova. The figures of the lion and the king in the upper left and right cartouches both represent gold in alchemical symbolism, and here probably also imply the male principle and the macrocosm. The figure at the lower right represents the queen and the two figures on the bottom, of whom the left is shown blind, represent the female principle and the microcosm. For Thurneisser, *see* N.B.G., xlv. Zinner, no. 2719.

28 ?FRENCH EQUATORIUM, *c.1600*

Brass, with iron pins. Diameter 266mm.

The face of the instrument consists of a fixed outer ring on which are engraved (reading from the outer edge inwards), a true zodiac scale graduated concentrically, and a non-uniformly divided eccentric circle used in conjunction with the lunar and solar epicycles. Within this is a scale of the lunar nodes which was used in conjunction with the scale on the rim of the movable disc. This disc is also engraved with fourteen tables for the positions and mean motions of the sun and moon. Over this disc rotates a pierced lozenge shaped disc, engraved with scales of lunar latitude. Over this pass the arms engraved with zodiac scales, carrying respectively two solar and lunar epicycle trains.

On the back, the instrument carries five planetary epicycles for Mercury, Venus, Mars, Jupiter and Saturn. On the limb is engraved a uniform scale for the ecliptic of date and a zodiac scale. On the large movable plate and a uniform scale of signs and degrees, and four series of concentric scales used to position the epicyclic discs of the planets. Over this rotate the five epicyclic discs with uniform scales. Near the centre is a zodiac scale, and the instrument is completed by a plate for the auges.

As an instrument designed to lessen the labours of computation, the equatorium was a complex device intended to give accurate results. The present example has been shown to display several signs of adaptation towards Copernican theory in its construction and calculation. Unique in this aspect, it is also one of the only two complete equatoria known, and has been described as 'the finest surviving example of a type of instrument which was gradually passing into obscurity'. *See* North.

Loaned by the City of Liverpool Museums.

29 ENGLISH TABLE CLOCK, *c.1595*. Globe *c.1830–40*

Case of brass; movement of brass and steel. Signed 'N. VALLIN'.
Diameter 120mm.

Plain drum clock, carrying terrestrial globe driven by a wheel of twelve teeth carried by the hour hand arbor, meshing with one of twenty-four carried on the inclined axis of the globe. The hour circle is fitted with touch pieces. The train is, crown wheel of thirty-one with a pinion of six taking into a contrate wheel of forty-eight with a pinion of ten, taking into a great wheel of sixty carrying the fusee of sixteen turns. A square stub on the axis of the great wheel which projects through the top plate carried a pinion of eight driving a wheel of sixty-four which drove the hour hand. This gives a period of twenty-four hours for the sixteen turns of the fusee.

On the inside bottom cover are engraved the following owners' names:

'JOHN T. DESAGULIER: LLD LECTURER on NAT et
EXP PHIL: LONDON: MDCCXXIX
Benjamin Franklin LlD; FRS, 1757
James Ferguson FRS, 1766
KENNETH McCULLOCH, 1774'

See Lloyd & Drover. [SGW]

Loaned by the Banff Museum.

30 UNIVERSAL ASTROLABE, *late seventeenth or early eighteenth century*
Brass. Origin unknown. Diameter 148mm; thickness of plate 4mm.

Single plate engraved round the edge with a scale of degrees (0–90/90–0 twice). Within this is a projection of the sphere of the form known as the Roias-type, for use in any latitude, first described by Hugo Helt the Frisian in the sixth book of Juan de Roias, *Commentariorum in astrolabium . . . libri sex*, Paris 1550. Over this, and for use with it, rotates a graduated *regulae* with a sliding cursor which is also graduated. On the back are engraved a degree scale in four quadrants (0–90/90–0), an hour scale (1–12 × 2), a zodiac calendar of concentric type and a shadow square with four sides. An alidade is fitted to the back. The suspension ring is fitted to an unusual gimbal mounting screwed to the rim of the plate.

A carefully designed and well executed astrolabe which eschews unnecessary decoration, is clearly divided and is easy to read. The general austerity of the instrument and its severely practical design suggest that it may be French or possibly English. While the fact that it is made according to the Julian calendar perhaps suggests a Protestant origin, comparable gimbal mountings for the suspension have so far been found only on instruments of French origin. The four-sided shadow square, although not unknown, is also uncommon.

For the use and description of the Roias-type astrolabe *see* Michel (1), pp.20, 103–4; for Hugo Helt *see* Maddison (2).

31 ENGLISH ASTRONOMICAL BRACKET CLOCK, *c.1685*
Movement of brass and steel; case of oak with ebony veneer. Signed 'Sam WATSON, LONDONI FECIT'. Height 890mm; diameter of dial 279mm.

The dial represents the geocentric system. The outermost ring gives the time of sunrise and sunset. The next ring shows the months of the year with the corresponding signs of the zodiac. This ring revolves in a clockwise direction once in 365 days and carries round a fixed image of the sun with pointer. This image has been moved from 10th to 21st December at some time after 1752 when the adjustment from the Julian to the Gregorian calendar was made in England. Inside this is the chapter ring with two-minute sub-divisions, the time being indicated by a single hour hand. The brass lunar dial within this chapter ring revolves clockwise in 29½ days, and contains a lunar phase aperture. Engraved on the ring also are lines for trine, quadrature, sextile and opposition of the moon. The innermost set of seven rings show the times for setting of the moon during the first half of the lunation, and the times of rising for the second half, each ring referring to different months.

Eight-day movement, wound from the back. Recoil escapement with a later pendulum. The calendar and lunar dials are driven from the hour hand arbor which carries a pinion of fifteen leaves. The swivel base is a later addition.

The gearing for the calendar ring is: 60/15 × 80/8 × 146/8 = 730 revolutions of the twelve hour hand = 365 days

and for the lunar dial: 60/15 × 118/8 = 59 revolutions of twelve hours hand = 29½ days.

Ownership of this clock has been credited to Sir Isaac Newton on the basis of a manuscript list of 1819 which describes it as 'Sir Isaac Newton's 8 days table clock'. Support for this association has been claimed from the fact that a cherub with telescope is shown on one of the two engraved plates added at the bottom of the backplate to raise the movement in the case. There is no evidence to support this claim.

Samuel Watson (*c.*1635–1711) seems to have made a number of astronomical clocks, selling one to Charles II in 1682. Appointed Mathematician in Ordinary, a second astronomical clock by him was purchased by Queen Mary in 1690, and was mentioned by John Smith two years later in his *Horological disquisitions* (see no. 33). [SGW]

See Lloyd (1, 2 & 3).

Loaned by the Worshipful Company of Clockmakers of the City of London.

32 HOROLOGICAL / *DIALOGUES*, / In Three Parts. / SHEWING / The Nature, Use, and / right Managing of / CLOCKS / AND / WATCHES / WITH AN / APPENDIX / Containing Mr *OUGHTRED'S* / Method for Calculating of Numbers, / The whole being a work very necessary / for all

that make use of these / kind of Movements. / [rule] / By *J.S.* Clock-maker. / [rule] / *London*, Printed for *Jonathan Edwin* at the / *Three Roses* in *Ludgate-street*, 1675. / [The whole contained in a single rule frame].

Duodecimo, pp.12 + 120. Collation: A–H8, I4. Title page on A2*r*, separate title page to Appendix on H2*r*.
Wing, S4105; Baillie, pp.103–4.

John Smith (*ante* 1673–1726) is said to have been a Lancashire tool cutter, who moved to London where he seems to have been making dividing engines by 1680. Besides clocks and watches he wrote on barometers, oil and water-colour painting, and advocated hydro-therapy (the 'cold water cure'). A unitarian, he was summoned before the Bishop of London's court in January 1695 and forced to abjure a theological tract he had published denying the Trinity. His *Horological dialogues*, a short elementary description of the various types of clocks and watches, was the first work in English entirely devoted to the subject.

33 Horological Disquisitions / Concerning the / NATURE of TIME, / AND THE Reasons why all Days, from Noon to Noon, are not alike / Twenty Four Hours long. / . . . / With TABLES of EQUATION, and / Newer and Better RULES than any / yet extant, how thereby precisely to adjust / ROYAL PENDULUMS, . . . / With a TABLE of PENDULUMS, / . . . / [rule] / By *JOHN SMITH*, C.M. / [rule] / To which is added, / The best Rules for the Ordering and Use / both of the Quick-silver and Spirit Weather- / Glasses: And Mr *S. Watson*'s Rules for ad- / justing a Clock by the *Fixed Stars* / [rule] / *LONDON:* Printed for *Richard Cumberland* at / the Angel in S. Paul's *Church-Yard.* 1694. / [The whole contained in a double rule frame].

Foolscap octavo, pp.4 + 92. Collation: A2, B–F8, G6. Bound between A1*v* and A2*r* is a double folding printed sheet printed on one side in black and red with two tables. Rebound half-leather and marbled boards.
Wing, S4106; Taylor, no. 497; Baillie, p.120.

John Smith's work on the inequality of time was produced to resolve the confusion caused by the fact that accurate clocks failed to go exactly with the sun. It thus provides a further example of the process of popular education in elementary astronomy exhibited in Moxon's work on the globes (no. 34).

34 A TUTOR to / *ASTRONOMIE* and *GEOGRAPHIE.* / Or an Easie and speedy way to know the / USE of both the / GLOBES, / *Coelestial* and *Terrestrial.* / In six BOOKS. / . . . / With an Appendix shewing the use of the *Ptolemaick Sphere.* / [rule] / The Second Edition, Corrected and enlarged. By *Joseph Moxon*, Hydrogra- / pher to the Kings most Excellent Majesty. / [rule] / Whereunto is added the Antient *Poetical Stories of the Stars:* / shewing Reasons why the several shapes and forms are pictu- / red on the *Coelestial Globe.* / As also a *Discourse* of the *Antiquity, Progress and Augmentation* / *of Astronomie.* / [rule] / [quotation from Job, 26:7:13] / [rule] / LONDON, Printed by *Joseph Moxon* and sold at his / Shop in *Russel street*, at the signe of *Atlas.* 1670. /

With additional engraved title-page in Latin at A1*v*. Collation: A–Oo4. Pp.5 + 272 + contents at end. Author/publisher's catalogue of books and instruments at Mm4*v*. Ownership inscription of 'Dan: Fleming' and shelfmark 'G3, 13' on fly leaf, with underlinings in pencil and a few ms annotations in ink which are probably by Fleming. Original calf.
Wing, M3023; Taylor (1), no. 256.

Moxon's treatise on the globes, which was based on the system of Tycho Brahe, was one of the most popular of its period. First published in 1659, it had passed through at least five editions by 1700. Moxon himself (1627–1700) was a printer, publisher, book and scientific instrument seller, whose several publications range over the whole field of applied mathematics. In the popularisation of astronomical and mathematical knowledge, his books hold an important place.

Daniel Fleming (1633–1701) of Rydal Hall, Westmorland, whose copy this was, was a local landowner, MP, and antiquary. His interest in scientific, technical and astronomical matters, which can be seen growing from the late 1660's onwards, illustrates excellently the development of interest in those subjects among local gentry in England and elsewhere. It was this interest which produced the demand for the globes, clocks and other celestial models, produced in increasing numbers throughout the seventeenth and eighteenth centuries. The present book is probably one of a group for which Fleming paid James Cock 7s 4d on 8th May 1671.
See Taylor, pp.233–4; D.N.B.; McGrath, pp.1–11, 458.

35 GERMAN CLOCK SHOWING 'SUNDIAL' HOURS, *c.1660*

Photograph. Signed by Daniel Buschmann of Augsburg.

Bayerisches nationalmuseum, Munich.

36 ENGLISH LONG CASE CLOCK, *c.1700*

Black japanned and parcel-gilt case; movement of brass, steel and blued steel. Signed 'Edw Cockey, Warminster'. Overall height 3,480mm; width of hood 770mm.

Twenty-four hour dial of which the central rings indicate the day of the month, month of the year, rising and setting of the sun, age and phase of the moon and sidereal time. Around these revolves a figure of the sun which rises and sets below artificial 'horizons' which adjust for the time of the year. The hour is indicated by the upraised arm of Father Time, the age of the moon by his right foot. His left foot indicates the sun's position in the zodiac. Although this clock has been associated with that presented to Queen Anne in 1705 (*see* B.M. Kings MS.277), there is no evidence available at present to confirm this attribution.
Loaned by the Trustees of the National Maritime Museum.

37 FRENCH ASTROLABIC CLOCK DIAL, *eighteenth century*

Brass. Signed 'Brulat & Thouret A Lyon'. Size of square 262mm.

Square plate with central circular aperture for the astrolabe, engraved with hour scale divided into quarters (1–12 × 2) with a flowing leaf decoration in the corners. *Rete* for twenty-one named stars, incorporating a star of David within the ecliptic circle, which has a raised rim round which the sun emblem attached to the rule/index travels. Latitude plate engraved with lines for the unequal hours. Surrounding the *rete* is a zodiacal calendar with pictorial representations of the signs of the zodiac. The *rete* and rule/index are held in place by a pin which passes through the second plate fixed to the back of the main plate, and secured by a horse (wedge).

Apparently intended as the dial of a clock, the absence of attachment marks on the back of the plate suggests that the instrument was never so used. The variations in the quality of the engraving, especially noticeable in the zodiac signs and pictorial symbols, suggest that it was not made by professional instrument makers but by two gentlemanly amateurs of science as an exercise.

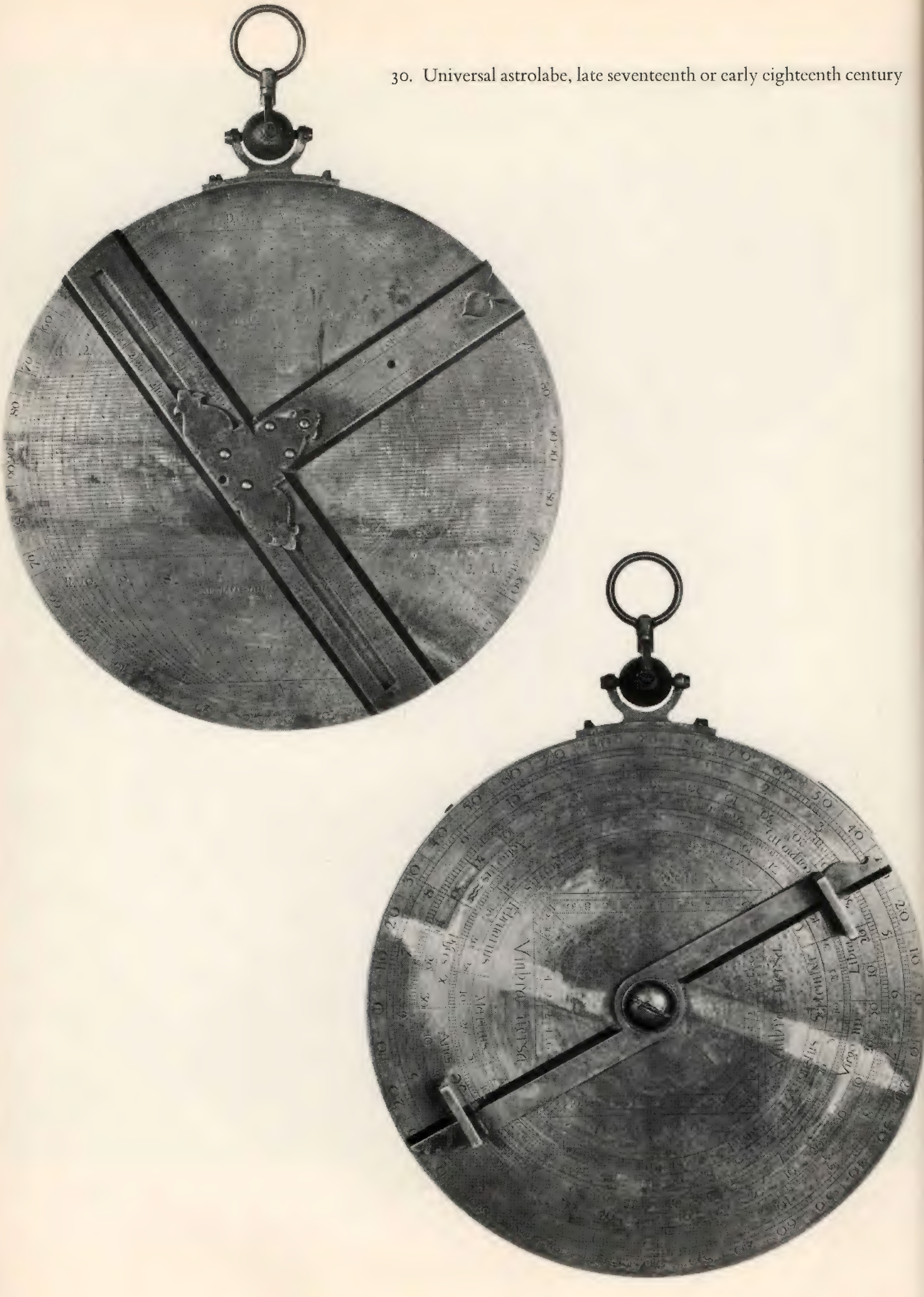
21. South German table clock, *c.*1560–70

22. Mechanical celestial globe, 157

22. Mechanical celestial globe, 1575

26. German planetary volvelles, *c.*1574–75

29. English table clock, *c.*1595. Globe, *c.*1830–40



30. Universal astrolabe, late seventeenth or early eighteenth century

31. English astronomical bracket clock, *c.*1685

37. French astrolabic clock dial, eighteenth century

Part 3. Enlightenment Consolidations

Newton's Cosmos

With the destruction of the traditional Aristotelian cosmology, it became a problem for astronomy why the planets remain fixed in their courses. What was the mechanism that kept them there? Why did bodies fall? If like matter always attracts like, why did not earth and moon rush to unite with each other? The answers proposed to these questions during the seventeenth century were many and varied. For William Gilbert (1540–1603) magnetism, which he had identified in the earth, seemed to supply an explanation of heaviness, and so of fall. To Kepler, who explored the attraction of one body for another, it was 'the aerial or other equivalent forces' inherent in earth and moon which held them in their places, while it was emanations from the sun which pushed the whole solar system round. The most influential cosmological system of the century however was that of Descartes in which matter of various kinds is considered to fill all space. Only gross bodies, which are opaque to light, are seen by men, and so the aether which makes up the heavens is invisible. This however is the substance which carries the planets round in a vortex caused by the swirl of the aetherial particles around the sun. Although Descartes' theory was incapable of empirical verification and has been justly characterised as 'a triumph of fantastic imagination which happens, unfortunately, never once to have hit upon a correct explanation',[79] it had considerable appeal in the middle decades of the seventeenth century thanks to its purely mechanical basis which excluded all the mystical and unexplainable forces postulated, for example, by Kepler. That Newton would ultimately be unable to explain gravity as a physical phenomenon, was one of the reasons for Leibniz's claim that the *Principia* weakened mechanical philosophy.

For in the *Principia mathematica philosophia naturalis*, Newton ignored the need for a physical hypothesis of the heavens, in order to concentrate on the mathematical theory which alone could explicate the dynamics of the heavenly motions. Conceiving of the planets as a set of bodies moving in a single dynamic system, Newton set himself to analyse the mathematical relations which existed between them. Doing so, he was able to show that the whole system depended upon the universal, centripetal force of gravity obeying the inverse square law. The vast observed complexity of astronomical movements had at last been reduced to order and dependence upon a single force. The elliptical orbits of the planets around the sun; the relationship of the earth and moon; the theory of the tides; the behaviour of a small body close to the earth's surface; the theory of Jupiter and its satellites and the attractive effects of each planet upon the others' courses could all now be resolved using the theory Newton provided. The problem set by Plato seemed to have been solved.

Yet if the *Principia* can be seen as the culmination of the Greek geometrical tradition, it did not supply a physical explanation of the universe. However well it showed how the planetary system operated, it did not explain why, nor could it explain what gravity was. It was this failure that led to Leibniz's criticisms and to the controversy between him and Newton's champion, Samuel Clarke (1684–1750).[80] In consequence it was not until after about 1720/30 that the Newtonian synthesis began to make general headway against the authority of Descartes. When it did so the essentially mathematical theory of the solar system became curiously intermingled with the more empirical and experimental approach which Newton had adopted in the study of *Opticks* (1704) and in his more private chemical researches.

The world of Newton was a world of law. As A. Rupert Hall has described it, 'Nothing happens by chance, nothing is arbitrary, nothing is *sui generis* or a law unto itself.

The philosophy of both *Principia* and *Opticks* insists that however varied, disconnected and specific the almost infinite range of events in nature may seem to be, it is so in appearance only: for in reality all the phenomena of things and all their properties must be traceable to a small set of fundamental laws of nature, and by mathematical reasoning each of them is deducible again from these laws, once they are known.'[81] An assured world such as this clearly could only have been produced by an omnipotent creator, 'This most beautiful system of the sun, planets and comets', Newton thought, 'could only proceed from the command and dominion of an intelligent and powerful Being'.[82] So man should wonder at it and admire, and doing so worship the divine author. Still, God accepted of a rational sacrifice, as Power and Browne had pointed out, and trying to understand his works was one very suitable. But the *Principia* was difficult and incomprehensible to most. Simpler works, and easy models, were needed for most men to begin to understand. It was in this process of popularisation that the orrery triumphed. Combining elegance as furniture with practical usefulness as a demonstration device, it represents the essence of the Enlightenment's pragmatic rationality.

Orreries and Affluence

In 1746 James Ferguson protested against the rise of the word orrery, 'a very improper name'. Better he thought was a phrase such as celestial atlas, Copernical sphere, or as Dr John Theophilus Desaguliers (1683–1744) rightly called it, the planetarium.[83] The early instrument of Tompion and Graham is traditionally supposed to have been made for Queen Anne, who presented it to Prince Eugene of Savoy. Richly made of expensive materials, it showed only the earth and moon system in relation to the sun, and is thus rather a *tellurium* than a planetarium in the common sense of the word. The instrument however was soon developed. Following Rowley's copy in 1712 [45] of the Tompion and Graham type of instrument [44], Thomas Wright, who was associated with Rowley, and for eight years shared premises with George Graham in Fleet Street,[84] combined the simple tellurium showing the monthly, diurnal and annual motions of the earth/moon system with a model showing the planetary paths and periods to produce the complex and expensive 'Grand Orrery'[47].

By the mid-eighteenth century, the orrery was well established, both as an opulent piece of furniture and as a valuable teaching aid. Following the demonstrations of Newton, astronomy and mechanics were fashionable subjects as such works as John Harris' *Astronomical dialogues* (1719) [46] and Benjamin Martin's *The Young gentleman and lady's philosophy* (1759) [50] illustrate. Lectures on philosophy such as were pioneered by John Keill (1671–1721) and Desaguliers, illustrated by elaborate demonstration models and experiments, rapidly became popular, finding a place in the universities and supporting numbers of independent lecturers in London and elsewhere.[85] Desaguliers used an orrery of his own design in the lectures and demonstrations that he gave in Oxford from *c.*1710, and in London from *c.*1713. Orreries in general however were expensive, prestigious symbols to be afforded only by wealthy patrons and large corporations. So also were the more traditional armillary planetaria which following Rowley's experiments, continued to be developed. In *c.*1705 the antiquary William Stukely (1687–1756) described an armillary model which had been made by the physiologist Stephen Hales (1677–1761). The London instrument maker Richard Glynne (*ante* 1696–1755) seems to have specialised to some extent in this form of model, producing his first example with wheel work in about 1740. But whether new orrery or traditional armillary sphere, the price of the large and sumptuous instruments remained high, and smaller, less expensive instruments were developed. Benjamin Martin (1704–1782) for example claimed to have deliberately set out to develop less expensive forms of the orrery,[86] and this was also James Ferguson's intention [74] as he eschewed expensive cases and complex gearing in the interests alike

of accuracy and cheapness.[87] By the third quarter of the century, the range of instruments available was considerable. Benjamin Martin for example listed orreries at prices ranging from £12 12*s* to £150 in his 1766 catalogue.

Even so there was scope for still simpler and cheaper models – a fact of which William Jones took advantage in designing his New Portable Orrery, made by W. & S. Jones from about 1784 onwards. This, a device stripped to the essentials necessary for teaching elementary astronomy to children [74] was highly successful selling at prices between three and six guineas. The more sumptuous instruments however could still be obtained, and it only underlines the importance of the orrery in eighteenth century social life that in a catalogue of *c.*1814, W. & S. Jones could list 'planetariums and orreries in great variety, the motions by wheelwork, exemplifying all the motions and phenomena of all the planets from £40 to £1,000'.[88]

The Divine Clockmaker

In his introduction to the second edition of the *Principia*, Roger Cotes categorically dismissed probabilism.

> 'The business of true philosophy is to derive the natures of things from courses truly existent; and to enquire after those laws in which the Great Creator actually chose to found this most beautiful Frame of the World; not those by which he might have done the same, had he so pleased. It is reasonable enough to suppose that from several causes, somewhat differing from each other, the same effects may arise; but the true cause will be that, from which it truly and actually does arise; the others have no place in true philosophy. The same motions of the hour-hand in a clock may be occasioned either by a weight hung, or a spring shut up within. But if a certain clock should be really moved with a weight; we should laugh at a man that should suppose it moved with a spring, and from that principle suddenly taken up without further examination, should go about to explain the motion of the index; for certainly the way he ought to have taken should have been, actually to look into the inward parts of the machine, that he might find the true principle of the proposed motions.'[89]

To the popular mind it was exactly this looking at the inward parts that Newton seemed to have done. The whole universe was revealed as law-like and consistent. The design of the world displayed the all-pervasive mind of its creator at work.

When Cicero invoked the sphere of Archimedes in his Tusculan oration, he did so in order to strengthen his arguments for the existence of a sentient creator, and of a divine soul in man.

> 'When Archimedes described in a sphere the motions of the moon, sun and five planets, he did the very same thing as Plato's God, in his Timaeus, who made the world; causing one revolution to adjust motions differing as much as possible in their slowness and velocity. Now, allowing that what we see in the world could not be effected without a God, Archimedes could not have imitated the same motions in his sphere without a divine soul.'[90]

Just as Archimedes' success supplied the basis for natural religion, so Newton's success in laying down a mathematical model of the universe brought certainty to man's knowledge of physical phenomena and implied the existence of a creator.

The argument from design as a proof of the existence of a wise and beneficient creator was a common one in the age of Newton. The clockwork metaphor reinforced it, and the mathematics of the *Principia* guaranteed the accuracy of the laws upon which it depended. God, thought Benjamin Bridgewater, 'has fix'd the Laws of *Loco-motion* in Corporeal Substances, and ty'd up the *Primum Mobile* it self to a certain Proportion of Time and Distance, which it can no more exceed, than the smallest *Wheel* of a Watch.'[91]

It was Alexander Pope, of course, who most elegantly summed up in the epigram intended for Newton's epitaph the transformation that seemed to have wrought

'Nature, and Nature's Laws lay hid in Night.
God said, *Let Newton be!* and All was *Light*.'[92]

It merely underlines the confidence that the eighteenth century felt, that it was this same knowledge of the celestial movements that Pope should at once exalt and scold in the *Essay on Man*,

'Go, wond'rous creature! mount where Science guides,
Go, measure earth, weigh air, and state the tides;
Instruct the planets in what orbs to run,
Correct old Time, and regulate the Sun; . . .
  Superior beings, when of late they saw
A mortal Man unfold all Nature's Law,
Admir'd such wisdom in an earthly shape,
And shew'd a NEWTON as we shew an Ape.'[93]

Yet if the eighteenth century was God-like in its comprehension of the reasons of the universe, only a very few men were really able to understand. Most, like Tristram Shandy, journeying to Lyons to see 'the wonderful mechanism of this great clock of *Lippius* of *Basil*' recognised that comprehension of it was beyond them. Tristram confessed that 'of all things in the world I understand the least of mechanism – I have neither genius, or taste or fancy', a brain, 'entirely unapt for everything of that kind'.[94] Even so he continued to wonder at and delight in the Lyons clock. Similarly with God's vast clock of the world. Few men could understand Newton's work, or the issues raised in the controversy with Leibniz. None the less like Locke, who having checked with Huygens that the geometry was acceptable, proceeded to take it on trust,[95] they were anxious to accept the natural philosophy. With d'Alembert eventually they could believe that 'the true system of the world has been recognised, developed and perfected'.[96] With this recognition came a surge of confidence such as had not been experienced in Europe for the previous three centuries. It is this confidence, even serenity, which is reflected in the orreries and planetary clocks of the eighteenth century and early nineteenth century. Elegantly, they displayed a settled, perfect system which the great God established and permitted man to understand. Pope and the moralists might insist on the contrast between man's knowledge of the heavens and his ignorance of his own actions, and so preach the lesson of humility. Leibniz and Clarke might argue abstrusely about whether it was a derogation of God's power to imagine him occasionally intervening in the operations of the world in order to repair the machine, or whether, having made it perfectly at first, it needed never again to be altered. For most men however such matters were of no importance. The idea of the stupendous heavenly clock inspired, as it was intended, awe and admiration while the domestic clock or watch supplied an everyday symbol for perfection. In itself it illustrated the abundance of goodness which might follow from a single impulse of piety, just as the variety of the heavens, the concord of the body and the inclinations of the soul, followed from a single principle.

'Could but our tempers move like this machine
Not urged by passion, not delayed by spleen,
And true to natures regulating power,
By virtuous acts, distinguish every hour
Then health and joy should follow as they ought,
The laws of motion and the laws of thought
Sweet health to pass the present moment o'er
And everlasting joy when time shall be no more.'[97]

Part 3: Exhibits

38 PHILOSOPHIAE NATURALIS PRINCIPIA MATHEMATICA

Auctore Isaaco Newtono, Eq. Aurato. Perpetuis Commentariis illustrata, communi studio PP. Thomae Le Seur & Francisci Jacquier. Three vols, Geneva 1739–42.

Quarto, contemporary paper boards, new fly leaves, title in red and black with vignettes. Vol.i, pp.xxxvi + 548; vol.ii, pp.8 + 422 + index and errata; vol.iii, pp.8 + 703, partially uncut. Signature of 'Carlo Belloni' on title page of vol.iii. Included in vol.iii are: Daniel Bernouilli, *Traité sur flux et reflux de la mer*; Colin Maclaurin, *De causis physica*; Leonhard Euler, *Inquisitio physicae.*

Babson, 30; Gray, 13.

Commonly known as the first Jesuit version, although the editors were both members of the order of Minîmes, this edition of the *Principia* was important for the valuable commentaries attached to it. The three works published with it constitute all the work of importance done on the theory of the tides between Newton and Laplace. The text is that of the third English edition, with the prefaces from the earlier editions, Roger Cote's preface, and Edmond Halley's revisions.

39 MEDAL OF SIR ISAAC NEWTON, *1731*

Silver. Signed on obverse 'I.C.' [John Croker].

On the *obverse* is a portrait bust of Newton facing left surrounded by the legend, 'ISAACVS NEWTONVS'. On the *reverse* is a figure of winged science (?Urania) leaning against a table looking towards the right and holding a tablet on which is a representation of the solar system. In a semi-circle above is the motto '*Felix cognoscere causas*'.

The date at the bottom of the reverse, MDCCXXVI, is that of Newton's death, old style. The medal was struck at the Tower of London five years after his death, and with the portrait medal produced by Roettiers, is among the best likenesses of Newton produced by medallists. *See* Smith, no. 1 and p.12; Babson, no. 578.

40 AN ACCOUNT OF SIR ISAAC NEWTON'S PHILOSOPHICAL DISCOVERIES,

in four books. By Colin Maclaurin . . . published from the author's manuscript papers by Patrick Murdoch. London, printed for the author's children, 1748.

Quarto, pp.xx + 392, six folding plates, list of subscribers' names and life of author, original calf. Pp.xvii–xviii have been misplaced between b4*v* and c1*r* of the subscription list.

Babson, 85; Gray, 112.

Colin Maclaurin (1698–1746) was perhaps the one mathematician of the first rank produced in Britain during the eighteenth century. Born at Kilmadan, he was orphaned at ten years old. In 1717, he became Professor of Mathematics at Marischal College, Aberdeen, and in 1719 met Newton in London and became F.R.S. In 1724 he moved to Edinburgh, where he quickly became an influential figure and leading citizen, organising the defence of the city during the rising of 1745. It was this however which ruined his health and caused his death in the following year. His lucid account of Newton's work was published two years later and received two further English editions and a French translation in the course of the eighteenth century.

41 ROHAULT'S SYSTEM OF NATURAL PHILOSOPHY,

illustrated with Dr Samuel Clarke's notes, taken mostly out of Sir Isaac Newton's Philosophy. With additions. Done into English by John Clarke D.D. Dean of Sarum. Second edition, two vols, London 1729.

Octavo, full calf. Vol.i, pp.xxii + 285 + 3 (publisher's catalogue) + two folding engraved plates. Vol.ii, pp.292 + index + fifteen engraved folding plates.

This edition not in Babson or Gray.

The system of natural philosophy of Jaques Rohault (1620–1673), was one of the leading textbooks of Cartesian philosophy and was used at Cambridge until late in the eighteenth

century. In Clarke's edition however, it became a vehicle for the dissemination of Newton's ideas, since Clarke refuted the Cartesian text in his commentaries and footnotes. Clarke's Latin translation was first published in 1697, and the English edition in 1723. A third edition appeared in 1735. The book thus played an important part in the gradual spread of Newtonian cosmology. *See* for the context, Hall, pp.307–20.

42 A VIEW OF SIR ISAAC NEWTON'S PHILOSOPHY

By Henry Pemberton. Dublin, printed for William Williamson Bookseller at Mecenas Head in Bride St, 1756.

Demy octavo, pp.44 + 333, ten folding engraved plates. New calf. Bookseller's catalogue on the verso of title page; subscription list.

Henry Pemberton (1694–1771) was employed by Newton to supervise the third edition of *Principia* in 1726. F.R.S. in 1720 and Gresham professor of Physic, 1728, his popular account of Newton's system, which first appeared in 1728, was a successful and important popularising work.

This edition not in Babson.

43 UNIVERSAL EQUINOCTIAL RING DIAL AND ASTROLABE, *c.1700*

Silver. Signed 'WERNHER *fecit*'.

An unusual form of ring dial in which the bridge is replaced by a disc engraved on the face with a degree scale and a form of sundial employing a Rojas projection. On the back is a degree scale, zodiacal calendar and declination scale. The face is fitted with a sliding cursor and the back with an alidade. For use in northern and southern latitudes.

From a private collection.

44 ENGLISH ORRERY, *c.1710*

Brass, ebony and silver, with the top plate covered with blue-green vitreous enamel; movement of brass and steel; outer case of ebony and glass, lined with original green velvet.

Octagonal case with bracket feet. The silver outer ring on the top is engraved with three circles, the outer being divided with the signs of the zodiac, the second having the month names in Latin, and the third the days of the month. Within this ring rotates an enamelled plate carrying models of the sun, the earth (which is engraved with a map), and the moon which has one side blackened. Also attached to the plate are two pointers for indicating the difference of date between the Julian and Gregorian calendars. On one side of the case is a clock face with chased and pierced spandrels and having two concentric rings of figures in place of the usual dial (1–12 × 2). The outer of these rings is fixed, the inner movable and geared to show the difference between solar and sidereal time. In the centre of the dial is an arbor to which a cranked winder is attached. When this is turned the whole mechanism is actuated. The moon and earth rotate and revolve in their proportionate periods, while a pointer radial to the sun indicates the meridian of the earth at which it is noon. The crescent surrounding the earth indicates the regions of day and night, and is a replacement. With octagonal wooden outer case, with original locks.

See Gabb & Sherwood Taylor.

Loaned by the Museum of the History of Science, Oxford.

45 ENGLISH ORRERY, *c.1710–12*

Wood, brass, silvered brass and steel. Not signed, but by John Rowley. Diameter 762mm; height of case 350mm.

Circular case with gilt decoration of birds and flowers in the Chinese style. Mounted on the edge of the case is a horizon ring supported by twelve turned baluster pillars. This engraved with a zodiac calendar with diagonals. In the centre of the instrument is a brass sphere representing the sun in a glass domed case, around which revolves the earth/moon system, also in a glass domed case. A pointer at the side indicates the position of the sun in the ecliptic on the horizon ring. Attached to the side of the case is a nineteenth century brass plate with the inaccurate inscription,

'Orrery invented by Graham 1700
Improved by Rowley, and presented by
him to John, Earl of Orrery, after whom it was
named at the suggestion of Richard Steele.'

When the instrument is actuated (one turn of the handle equals twenty-four hours), the sun, which has its axis inclined to the ecliptic, passes through one revolution of its true equatorial period of twenty-seven and a half hours, the earth displays its diurnal motion and the parallelism of its axis, while the moon is shown, in its correct inclination, rotating round the earth and upon its own axis. The movement, which consists of a radial frame driven round a central stalk by a worm and worm-wheel, employs some epicyclic gearing. The fifty-nine tooth wheel for the moon's axial rotation is a replacement made in 1936–7 by R. T. Gould during his restoration of the instrument.

Made after the model of the Tompion & Graham instrument, or perhaps that by Graham, Rowley's planetarium, named after his patron, Charles Boyle, 4th Earl of Orrery, enjoyed great contemporary fame. First described, in its extended form with planets added, by John Harris in his *Astronomical dialogues* of 1719 (see no. 46), it immediately became an instrument which provoked other makers to emulate it. At the same time, the semi-satirical verses written by Claudian about the sphere of Archimedes, were reworked to apply to Rowley.

When lately Jove the ORRERY survey'd,
He smiling thus to Gods in Council said;
How shall we stint presuming Mortals Pow'r?
The Syracusan Sage did, once before,
The heavenly Motions shew in Spheres of Glass,
And the erratick Orbs and Stars express:
But his Machine by one fixt Pow'r and Weight,
Mov'd, and was govern'd, as we are, by Fate.
While the bold *Rowley* in his Orrery
Keeps his first Pow'r, just like his Genius free:
He knows the secret Springs; and can impart
Laws to the whole, and to each single part;
His daring Hand, or brings or hinders Fate,
Makes *Mercury* fly, or *Saturn* walk in State
He makes the Earth thro' silver *Zodiac* run
Justly obsequious to the *Golden Sun*:
While the bright Moon shining with borrow'd Light,
Marks out the Months, and rules the Sable Night.
And all obedient to his sole Command,
Turn round their Axes, as he turns his Hand:
Their *Phases* and their *Aspects* all display,
And at his beck, exhibit Night or Day:
He makes Eclipses as he will appear,
For any past, present, or future Year;
Shews their true Cause, and roots out vulgar fear.
Guiltless *Salmoneus* at your Suit I slew,
Shall I to please you take off *Rowley* too?
O! no! all cried; the glorious Artist spare,
Transplant him hither, and make him a Star.

See Gould; Harris, pp.159–84.
Loaned by the Rt. Hon. the Earl of Cork and Orrery.

46 ASTRONOMICAL DIALOGUES BETWEEN A GENTLEMAN AND A LADY: wherein the doctrine of the sphere, uses of the globes, and the elements of astronomy are explain'd in a pleasant, easy and familiar way. With a description of the famous instrument, call'd the Orrery. The second edition. By J[ohn] H[arris]. London 1725.

Octavo, pp.184, six engraved plates (four folding). Contemporary calf with joints neatly repaired.
Engraved bookplate of Sir Edward Blackett, Bt.
Taylor (1), p.284: Taylor (2), p.124.

First published in 1719 and the first book to describe the orrery. John Harris (1667–1719) was a mathematical teacher and lecturer in London, who became F.R.S. in 1696, and secretary of the society 1709–10. The purpose of this book, which was based on Fontenelle's, *On the plurality of worlds*, was, he said, 'The engaging Persons of Birth and Fortune in a warm application to useful and real learning'. In consequence, he taught only the truth. 'I don't perplex my Fair Astronomer with anything but the true System of the World: I mislead her by no Notions of Chrystalline Heavens, or solid Orbs: I embarrass her with no clumsy Epicycles, or imaginary and indeed impossible vortices: But I shew her at first the Celestial World just as it is; and teach her no Hypotheses, which, like some other things taught at Places of great Name must be unlearnt again, before we can gain True science.'

47 ENGLISH GRAND ORRERY, *c.1740–50*

Movement of brass and steel; case of ebonised oak with brass feet and horizon ring; deal base; outer case of ebonised oak with glazed panels and brass verticals; table of oak, mahogany and deal; glass dome. The interior of the inner case is painted red; the planetary rings originally blue have oxidised to a sea-green colour; gilt line for the planet's path. Signed on the 'clock' dial '*Made by* GEO ADAMS at TYCHO BRAHE'S HEAD, in *Fleet Street London*'. Overall diameter 1050mm.

Dodecahedral case, with pictorial representations of the signs of the zodiac painted on each face, each surrounded by a moulded rectangular frame. The movement is mounted on runners. From it the central driving arbor extends through one face of the case and may be turned by a cranked handle. The inferior and superior planets may be independently disengaged from the drive by withdrawing two rods projecting through the face on either side of the winding arbor. Two further rods projecting through the top of the case serve to lock this disengagement mechanism in place.

The top of the instrument is supplied by a set of circular, concentric nesting rings which carry round the planets, having their names and proper periods marked on the ring.

Saturn with ring and five satellites	29 years 168 days
Jupiter with four satellites	11 years 314 days
Mars	1 year 32 days
Earth with moon mounted on brass plate carrying a zodiac scale	period not given
Venus	225 days
Mercury	83 days

The sun is shewn with a number of indentations, perhaps to represent sun spots. A small circular inset plate may once have carried a noon pointer.

A twenty-four-hour and sixty-minute 'clock' dial is used to count the number of turns given to the winding handle (one turn equals twenty-four hours) and so to the mechanism. The 'hours' on the dial represent days and the 'minutes' hours. Round the edge of the instrument is a brass ring engraved with a zodiacal calendar supported on baluster pillars. Above this is an armillary hemisphere, the 'ARTICK CIRCLE' and 'TROPICK OF CANCER' being so named, and also showing the equator, the solstitial and the equinoctial colures. Surrounding this is a segmented glass dome.

Described by Adams in his 1746 catalogue as 'A Planetarium of about three Feet and a half Diameter, handsomely ornamented', the instrument showed the motions of earth and moon together round the sun, with the inclination of the moon's orbit and retrogradation of the nodes, the annual and diurnal motion of the earth and the motion of the sun round its axis. In addition the annual motion of all the planets was shown plus the diurnal motion for Venus, Mars and Jupiter and the motions of all the secondary planets round their primaries in their proper periods.

Provenance: Presented to the Sedgwick Museum, Cambridge, by Peter Mason A.M., Master of St John's College in 1904. Not part of the St John's College collection, but the private property of one of the fellows who kept it in his rooms as an ornament.

See Adams (1), pp.261–2; Adams (2).

Loaned by the Whipple Museum of the History of Science, Cambridge.

48 A TREATISE DESCRIBING THE CONSTRUCTION AND USE

of new celestial and terrestrial globes. By George Adams. Second edition, London 1769.

Octavo, pp.xxviii+345+catalogue of makers' instruments [7 pp], fourteen folding plates, engraved bookplate of Gilbert Hamilton. Contemporary calf repaired.

Having its first edition in 1766, the thirtieth edition of this extremely popular work appeared in 1810.

Taylor (2), p.152.

49 ASTRONOMY EXPLAINED UPON SIR ISAAC NEWTON'S PRINCIPLES,

and made easy to those who have not studied mathematics. By James Ferguson. Third edition, London 1764.

Quarto, pp.354+index, seventeen engraved folding plates. Full calf rebacked. Printed bookplate of Sidney Edelbar.

Babson, 58; Gray, 75.

50 THE YOUNG GENTLEMAN'S AND LADY'S PHILOSOPHY,

in a continued survey of the works of nature and art; by way of a dialogue. By Benjamin Martin. Three vols, third edition, London 1781.

Octavo, pp.8+408+index; vol.ii, contents+421+index; vol.iii, catalogue of maker's instruments for 1782+366+index, plates. Full calf.

51 AN INTRODUCTION TO ASTRONOMY

in a series of letters from a preceptor to his pupil. In which the most useful and interesting parts of the science are clearly and familiarly explained. By John Bonnycastle. Second edition, London 1787.

Octavo, pp.vi+437+advertisement, twenty-nine folding plates. Full calf.

Bonnycastle first published his astronomy in 1786. A popular introduction to the subject it received many editions. The work ends by quoting Newton's account of God from the general scholium to *Principia*, 'which he [and clearly Bonnycastle also] considered as the most proper conclusion for a work that consists chiefly in an attempt to investigate the laws by which this great Being conducts his operations, and regulates the machine of the universe over which he presides'.

52 ENGLISH ARMILLARY SPHERE, *c.1730*

Brass, with ivory sphere representing the earth. Signed 'THO: HEATH FECIT'. Diameter of horizon ring 218mm; overall height 277mm.

Removable sphere made up of arctic and antarctic circles; the tropics of cancer and capricorn; equator; ecliptic/zodiac and the equinoctial and solstitial colures which are divided in degrees. This is held in a contemporary meridian ring which appears to have been intended originally for another instrument. The earth is mounted on a rotatable brass rod, mounted at the ecliptic pole. The whole sphere is contained in a horizon ring engraved with a zodiacal calendar, which is rotatable on a turned single column which is mounted on an inverted domed base weighted with lead.

From a private collection.

53 ENGLISH EQUINOCTIAL RING DIAL, *c.1740*

Brass and silvered brass. Signed 'THO: HEATH LONDON'.

Circular base with three engraved scrolled feet, with levelling screws, two marked with an 'A'. Set into the base is a second plate with inset silvered compass surrounded by a double degree scale and having two bubble levels. This plate may be rotated within the base, and has engraved on its silvered surface a degree scale in four quadrants and an equation of time-table. Mounted on this plate is a meridian ring engraved on one side with a degree scale in four quadrants and

on the other with the latitudes of various towns. Within this is an equinoctial ring engraved on the face and inner edge with a twenty-four-hour scale and on the back with further latitudes of towns. The bridge is engraved with declination scales within a formal stiff-leaf border. Engraved on the edge of the suspension ring mount, which is adjustable for latitude, is a vernier scale. From a private collection.

54 ENGLISH INCLINING DIAL, *c.1725*

Brass and silvered brass. Signed 'B. Scott Fecit'. Size of square 73mm.

The latitude arc, marked with a crowned 'H' is a replacement. In original green velvet lined fishskin case.

55 ENGLISH INCLINING DIAL, *c.1740*

Silver. Signed 'I. Sisson *LONDON*'. Base 212mm square.

From a private collection.

56 ENGLISH LONG CASE CLOCK, *c.1730*

Movement of brass and steel; case of walnut veneered on oak. Signed 'Daniel Alan, London'. Overall height 2,760mm.

Unusual sunrise/sunset dial of which the outer ring is marked for the days of the month at five-day intervals. With this are two large rings each with three sets of numerals, the middle two sets representing minutes and the outer two, hours. The first of these two large rings gives ordinary sunrise and sunset by adding the minutes to the hour on the left for sunrise, and subtracting minutes from the hour on the right for sunset. The third ring supplies astronomical sunrise/sunset, i.e. when the sun is 18° below the horizon. These times are obtained in a similar manner, and the ring has a segment marked 'No Real Night' which refers to the period in midsummer when the sun fails to sink as far as 18° below the horizon in areas where the latitude and declination equal 72° North or over.

The fourth and fifth rings supply an equation of time dial, and the outer ring carries the months of the year. To the left is a universal tidal dial, and to the right a strike/silent dial.

Movement with three trains, striking on bells. The clock is clearly signed 'Alan' and not 'Man' as assumed by H. Alan Lloyd in a lecture on the clock entitled 'No real night'. [SGW]

57 ENGLISH ASTRONOMICAL BRACKET CLOCK, *c.1735*

Movement of brass and steel; case of ebony veneered on oak; dial of gilded and silvered brass. Height 381mm. Signed 'George Hayes, London'.

The circular astronomical dial in the arch contains two rotating engraved brass rings, a central blued steel disc which also rotates, and a fixed chapter ring of twice twelve hours, on the outside. This chapter ring is necessary to synchronise the astronomical dial with the main dial. The various indications are given as follows: the central disc rotates once in twenty-four hours and carries a thin pointer indicating the hour on the chapter ring. Diametrically opposite on the same disc is an effigy of the moon indicating its age on the next ring. This ring, engraved with the 29½ days carries an effigy of the sun and makes one extra rotation in that period, than the central disc. The sun pointer indicates on the wide rotating ring the time of sun rise, the declination of the sun, and its position in the zodiac to the nearest degree. This ring makes one more revolution in 365 days than the inner brass ring carrying the sun pointer.

The gearing for the astronomical work is driven from the centre pinion arbor through a series of wheels to a vertical pinion behind the front plate leading to a further train of wheels behind the astronomical dial. The drive is delivered by a wheel of sixty-one teeth revolving once in twenty-four hours. The subsequent gearing is as follows:

Zodiac ring $= 37/61 \times 43/27 = 1{\cdot}038004$ revolutions per day.

Age of moon ring $= 37/61 \times 54/34 = 1{\cdot}03520$ revolutions per day.

The movement with verge escapement strikes the hours. [SGW]

58 ENGLISH LONG CASE CLOCK, *c.1750*

Lancashire design case of mahogany. Signed 'Barker, Wigan'. Overall height 2,745mm.

This highly complicated clock was Barker's most famous work. The following information is displayed on the astronomical dial.

The outer ring represents twice twelve hours indicated by the sun effigy immediately below. Moving shutters indicate the times of sunrise and sunset against the next inner ring. The next scale indicates the amplitude and declination of the sun against the edge of the shutters. In the centre is a revolving moon indicating its phases and the times of high tide at Bristol, Hull, London and Dover. Below this is the indication for the equation of time. The main dial contains political and ecclesiastical commemorations indicated by a long hand revolving once a year. On the outside of the chapter ring is a circle with the Sundays in the Church of England calendar, next comes the days of the month and months of the year with the Saints' days. Also marked on this circle are the dates of the execution of Charles I, the restoration of Charles II and the Gunpowder Plot. Along the inner edge of the chapter ring are marked the signs of the zodiac. At the bottom of the dial is the dominical letter. The centre of the dial is engraved with the motto: 'The man is yet unborn who duely weighs the hour'. There is a barometer in the waist door. [SGW]

Loaned by Johann Klein, Esq.

59 ENGLISH TIMEPIECE, *c.1770*

Brass, silvered brass and steel. Signed '*Justin Vulliamy LONDON*'. Size of dial 241 × 188mm.

The dial has nine subsidiary dials for minutes, seconds, 1/8 seconds, second, third, and fourth seconds; and second, third and fourth minutes. Three of these dials at a time may be disengaged from the movement by three spring clutches. Weight-driven movement with cylinder escapement and 1/4 second pendulum suspended in friction wheels. The mechanism may be stopped or started at will. Possibly made for George III, for use in his private observatory at Richmond.

Loaned by R. K. Foulkes, Esq.

60 ENGLISH LONG CASE CLOCK WITH CELESTIAL PLANISPHERE, *c.1790*

Movement of brass and steel; ivory ball for moon; case of mahogany banded with kingwood and boxwood. Signed 'Thomas Lister Halifax'. Overall height 2,032mm.

The concave planisphere portrays the mythological constellations with the ecliptic and equinoctial circles and contains a calendar ring around its perimeter. It revolves once in a sidereal day displaying the current state of the heavens overhead, the southern sky being at the top and the northern at the bottom. An ivory ball representing the moon is carried mid-way along a pointer (revolving once in twenty-four hours) and indicating its position with its 27·3 day circuit against the ecliptic and its age in a lunation against the middle revolving ring. It also rotates to show the phases.

The astronomical trains are driven from the minute hand arbor, between the dial and the front plate which is set far back to allow for this. This arbor carries a wheel of forty teeth, the gearing being as follows:

Moon orbit hand: $40/80 \times 30/180 \times 180/18 \times 18/360 = 1/24$ Revolutions/Hours

Planisphere: $40/80 \times 30/180 \times 183/28 \times 365/28 = 1/23{\cdot}934424$ Revolutions/Hours

Lunation ring: $40/80 \times 30/180 \times 157/28 \times 325/28 = 1/24{\cdot}840774$ Revolutions/Hours

The ratio for sidereal time of the revolution of the planisphere is correct to the fifth decimal digit being 1:1·002739 as opposed to 1:1·002737. The movement strikes the hour with a count wheel and has an unusual pinwheel escapement. The case was originally part of a cabinet which housed the clock.

Thomas Lister (1745–1814) was one of the foremost makers of astronomical clocks.

See Loomes. [SGW]

61 ENGRAVING OF AN ARMILLARY ORRERY, *1755*

Signed 'A Perspective View of Mr H[a]wk[e]s's Orrery. Printed for J. Hinton in Newgate Street'.

62 AUSTRIAN ASTRONOMICAL CLOCK, *1770*

Photograph. Signed by Aurelius aS Daniele.

Bayerisches Nationalmuseum, Munich.

63 ENGLISH PLANETARIUM, *c.1800*

Brass, silvered brass and ivory; unsigned and undated terrestrial globe of printed gores pasted on a wooden core, coloured and varnished. Signed 'ADAMS LONDON'.

The body of the instrument consists of a silvered and toothed calendar plate, with an eight-point compass rose at the centre and a zodiacal calendar at the circumference. This calendar plate is the top of a cylindrical box which supplies the base of the instrument being supported on a single column carried by three folding cabriole-type legs. Inside the base is a geared mechanism, operated by a detachable ivory handled crank. This when turned allows the concentric planetary arms, which may be attached to the central shaft, to be rotated. A detachable brass sphere representing the sun attached to this central shaft is of diameter approximately 39mm. Alternatively the lunarium unit, with engraved and silvered base may be attached, to demonstrate the relative motions of the earth and moon.

The planetary arms with ivory spheres for the planets, which, with the exception of Uranus rotate round the sun in their proper periods, are in order outwards from the sun:

Mercury
Venus
Earth with one satellite
Mars
Jupiter with four satellites
Saturn with its ring and seven satellites
Uranus with six satellites.

In his 1789 catalogue of scientific instruments, George Adams listed 'The most complete Planetarium, tellurian and lunarium' at £36 15*s*. This instrument however did not show Uranus, Adams explaining that its period was too slow to be visible. In later editions however, the planet is discussed, together with the six satellites it was believed to have for a short time after 1798.

Dudley Adams (*c.*1760–1826), the maker of this instrument, was brother to George Adams the younger, and succeeded him in the family business after his death in 1795, but did not acquire his stock which was sold at auction to William Jones. This instrument is however extremely similar in style and detail to those produced by his brother.

For similar examples *see* Maddison (3), pp.94–5; Calvert, no. 15; Adams (2).

64 DESCRIPTION D'UNE SPHERE MOUVANTE

par le moyen d'une pendule d'une globe monté d'une façon particulière, & d'un nouveau planisphere pour les distances & grosseurs des planètes. Le tout selon l'hypothèse de Copernic. By Jean Pigeon and G. Le Roy. Paris 1714.

Octavo, pp.12+142+2. Two engraved plates, two figures with rotatable volvelles. Full contemporary calf. Ownership inscription of 'J. B. De La Rue 22 7bre 1732' on title page. Baillie, p.143.

A complete account of 'le profil de ce grand Univers', as Pigeon calls it. His machine demonstrated the periodic motion and relative proportions of the planets. The work also includes a description of a new planisphere showing these phenomena according to the Copernican system.

Loaned by M. Nicolas Landau.

65 LES USAGES DE LA SPHERE, ET DES GLOBES CELESTE ET TERRESTRE,

selon les hypothèses de Ptolémee & de Copernic, précédés d'un abrégé analytique sur leur origine, sur les differens systèmes du monde, & de la description de la sphère armillaire. By C. F. Delamarche. First edition, Paris 1791.

Octavo, pp.332+5 folding plates. Marbled boards, quarter leather.

66 FRENCH PTOLEMAIC ARMILLARY SPHERE, *c.1780*

Beechwood, brass and pasteboard, the rings covered with engraved and varnished paper; their circumferences painted in red. Overall height approx. 403mm.

Turned single stem stand on circular base carrying horizon ring with four supports engraved with the latitudes and longitudes of various places. Horizon ring with zodiacal calendar having pictorial representations of the signs of the zodiac. Into this slots the meridian ring carrying a four quadrant degree scale, and having a twenty-four hour dial at the north pole. Mounted within the meridian circle and free to rotate is a sphere formed of armillary rings (named) for the arctic, antarctic, the tropics of Cancer and Capricorn, the equator and the ecliptic/zodiac. The solstitial and equinoctial colures carry degree scales. On a spike in the centre of the rings is a terrestrial globe. Suspended from the ecliptic axis are strips carrying sun and moon emblems, rotatable in the plain of the ecliptic.

This sphere may be from the workshop of C. F. Delamarche, rue de Jardinet, no. 13, Paris. (See no. 65)

67 FRENCH COPERNICAN ARMILLARY SPHERE, *c.1800*

Beechwood, brass and pasteboard; the rings covered with engraved and varnished paper, coloured red, green and yellow. Overall height approx. 410mm.

Turned single stem stand carrying a sphere composed of rings for the solstitial and equinoctial colures, and the ecliptic/zodiac band on which the months and various signs are named in Italian. Central gilt globe for sun round which rotate four concentric rings mounted on the central axis and representing Earth, Mars, Jupiter, and Saturn. The earth on an inclined axis is shewn by a globe with meridian ring and hanging moon emblem. The proper periods of each planet shown are marked on the rings:

Earth	365 days, 5 hours, 49 minutes
Mars	1 year, 321 days, 22 hours, 19 minutes
Jupiter	11 years, 315 days, 14 hours, 12 minutes
Saturn	29 years, 163 days, 14 hours, 8 minutes

Although not signed, probably from the Delamarche *atelier*.

68 FRENCH MANTEL CLOCK, *c.1760*

Signed by Pierre Le Roy. Overall height 762mm.

The globe engraved with countries in the northern hemisphere, held in a basin with an Apollo mask in front, above which is the point where the noon line crosses the meridians. The cylindrical movement surmounted by a vase containing a revolving enamel ring giving the age of the moon.

Pierre Le Roy (1717–1785) was one of the most eminent of French horologists who played a major part in the development of the marine chronometer. [SGW]

Wernher Collection, Luton Hoo.

69 ELECTRIC ORRERY, *c.1780*

Brass and boxwood. Unsigned.

Long brass arm balanced on a brass rod (restored) pushed into the prime conductor of the frictional electrical machine. One end terminates in a large brass ball representing the sun, and the other in a sharp point which is bent upwards. On this balances a much shorter brass arm ending in a boxwood ball and a smaller brass ball, representing the earth and the moon. A short brass point projects sideways from each arm from which the electric charge streams when the whole arrangement is charged by the generator. This 'electric wind' causes the various arms and spheres to rotate, thereby simulating planetary movement.

As displayed, it is driven by:

SINGLE PLATE ELECTRICAL MACHINE, *c.*1830

Brass, glass, mahogany and leather. Signed, but rectangular nameplate is missing.

Polished mahogany base and uprights, supporting a 460mm diameter clear glass plate with brass axle and crank, and rubbed by four (two upper and two lower) adjustable square red-leather cushions with oiled taffeta flaps. Brass prime conductor on clear glass stem which slots into the front upright; its two semicircular brass arms ending near the glass plate in straight collectors. A Lane electrometer for controlling the electric shocks to the patient is secured to the side of the base. It consists of a glass stem with brass collar and ball-and-socket joint; its small brass rod and ball for picking up the charge from the prime conductor is missing.

ACCESSORIES

1. Insulating table. Overall height 211mm. Made of a natural finished mahogany board 327 × 280mm and four solid clear glass legs.
2. One straight and one curved medical director. Each one has a pear-shaped clear glass handle with brass rod ending in a 35mm diameter brass ball.
3. Medical Leyden jar. Clear glass jar with inner and outer tinfoil coatings. Mahogany lid through which protrudes a clear glass tube also coated internally and externally with tinfoil, and terminating in a large brass cap with central hook to allow the jar to be suspended from the prime conductor. Two brass wires (one missing) pass through holes in the cap and make electrical contact between the cap and the tinfoil coatings of tube and jar. Light shocks can be given to the patient from the charged tube, or stronger shocks by connecting him to the whole jar. The medical Leyden jar retains its charge much longer than the conventional jar.
4. Small turned mahogany amalgam box. A mercury amalgam was mixed with a little lard and spread onto the cushions of the electrical machine to increase the excitation. Two brass chains for connecting the medical directors to the electrical machine.

All the items are stored in a fitted red-stained deal box 574 × 395 × 690mm, with two iron carrying handles; unsigned and with no external markings.

The frictional electrical machine was first made in 1660, but its real development started in 1700. The plate machine was first made in the 1750's, and this particular type was designed by the instrument maker John Cuthbertson (1743–1822) in *c.*1799. In the nineteenth century this model was manufactured by a number of makers, including J. Cuthbert, W. & S. Jones and Wm. Cary, and its design remained virtually unchanged until well into the present century. This particular kit only contains medico-electrical accessories and therefore it must have been sold for therapeutic use. It was generally believed in the eighteenth century that electricity affected bodily functions and therefore many, such as the famous Methodist Minister John Wesley, thought that it could be used as a general medicament in disorders ranging from 'nervous headaches' to smallpox and blindness. Throughout the nineteenth century induced electric currents began to be primarily used in the treatment of wounded muscle tissue. The high voltage static electricity produced by the frictional electrostatic generator was, however, still used occasionally for home-treatment and by quacks.

See Brewster, vol.8, p.512 and pl.ccxlvii, fig. 8; Hackmann, pp.11–26.

70

ENGLISH PLANETARIUM, *c.1810*

Brass and steel; globe of printed and coloured paper gores on a (?)plaster core. Signed 'T:Blunt London'. Globe signed 'LANE'S Pocket *GLOBE* London, 1809'. Diameter of calendar plate 225mm; overall height 473mm.

The body of the instrument consists of a silvered and toothed calendar plate, with a twelve point compass rose at the centre, and a zodiacal calendar at the circumference. This calendar plate is the top of a cylindrical box which supplies the base of the instrument, being supported on a single brass column carried by three folding cabriole-type legs. Inside the base is a geared mechanism, operated by a detachable, ivory-handled, crank. This, when turned, allows the concentric planetary arms which may be attached to the central shaft, to be rotated. A brass sphere to represent the sun may be attached to this central shaft. Alternatively the lunarium or tellurium fitments may be attached.

The planetary arms, with ivory spheres for the planets, are in order outwards from the sun:

Mercury
Venus
Earth with the moon
Mars
Jupiter with four satellites

Saturn with its ring and six satellites
Uranus

At a later date the central shaft has been modified to carry two further planet arms.

71 COPERNICAN ARMILLARY SPHERE, *nineteenth century*

Wood, brass and iron. Overall height 569mm; diameter of horizon ring 385mm.

Removable iron sphere with rings for the Arctic circle, tropic of Cancer, equator, ecliptic and zodiac band, tropic of Capricorn, and Antarctic circle. Each ring has a paper covering bearing its name. The zodiac ring is painted blue, with symbols and names of the individual signs in ochre. The sun, represented by a boxwood sphere, is carried by a brass rod passing through the poles, the earth and moon, being carried on a subsidiary arm from the same rod. The sphere is held in a red-painted meridian ring slotting into a horizon ring of iron covered with paper bearing a degree scale and zodiacal calendar. The whole is mounted on a three foot stand, with applied gilt-brass *oiseau* decoration and claw feet, on a triangular red varnished wood base, with inset silvered compass.

72 MECHANICAL EXERCISES:

shewing how to construct different clocks, orreries, and sun-dials, on plain and easy principles. By James Ferguson. Second edition, London 1778.

Octavo, pp.272, engraved frontispiece of the author and eight folding plates. Rebacked calf.
An important work in which Ferguson described the mechanical arrangement of the various clocks and orrery devices which he had invented.

73 ENGLISH ORRERY, *c.1810–20*

Movement of brass and steel; mahogany base overlaid with printed paper, coloured and varnished. Signed '*Designed for the NEW PORTABLE* ORRERIES by W. Jones *and made and sold* by W. & S. JONES, 30 *Holborn, LONDON*'. Diameter 320mm.

Circular base covered with a paper printed round the edge with a zodiac calendar. Contained within this in the upper half of the circle is '*A TABLE of the principal AFFECTIONS of the* PLANETS', published by W. & S. Jones in 1794, showing the distances, periods, sizes, etc, of the planets out to Saturn. In the lower half of the circle is a pictorial representation of the solar system. A brass sphere representing the sun is mounted on the central shaft around which revolve the inferior planets represented by ivory spheres, and the earth and moon. The moon is mounted over a silvered zodiac scale, with a silvered dial carrying a lunar phase diagram below. The whole machine is operated by turning a cranked handle which may be attached to an arbor below the base-board, meshing by an endless screw to a wheel attached to the central shaft of the movement which is carried through the base.

74 ENGLISH ORRERY, *c.1812*

Movement of brass and steel; mahogany base covered with printed paper, coloured and varnished; planetary arms of brass with ivory spheres for the planets; two carrying cases of mahogany. Signed 'A NEW PORTABLE ORRERY *Invented and Made by W. JONES* and sold by him in Holborn, *LONDON*'. Diameter 330mm.

Circular base overlaid with paper printed with a zodiac calendar and the four seasons together with the length of day and night and the equinoxes. In the central circle are pictures of the planets each drawn in a 'proportion as near to each other as possible, and that of a globe of the diameter of the board for the sun'. The instrument may be assembled either as a tellurian, (i.e. to show the relationship of earth and moon round the sun) or as a planetarium. For use as the latter, six arms which are attached by collars to the central axis carrying the sun may be put in place. The planets shewn are Mercury, Venus, Earth with Moon, Mars, Jupiter with four satellites, Saturn with ring and five satellites. A small brass ball which was used to represent the sun if the instrument was set up to show the Ptolemaic system is now missing.

For use as a tellurium, a frame containing four wheels, earth, moon and sun is screwed into place on the central axis. The earth with its axis inclined at 23½° is engraved with the Arctic, Antarctic and tropical circles, the equator and twenty-four meridians. It is surmounted by a 'terminator', as Jones called it, to show the boundaries of light and dark. The moon is geared to move round the earth in its period of 29½ days, and is given its proper inclination by the hinged ring below. Beneath this is an ecliptic ring for showing the moon's position, and below this a card showing the lunar age and phases.

Engraved on the tellurium frame is the inscription 'Monthly Preceptor No. 2 *To Miss Elizth Parker Aged* 14 *of Mettingham, near Bungay Suffolk as the Reward of distinguished Merit*'.

The planetarium attachment is contained in its own mahogany box which fits with the instrument into the outer case. Accompanying the instrument is a copy of the original instruction book, *The Description and use of a New Portable Orrery on a simple construction representing the motions and phenomena of the planetary system* [. . .] *to which is prefixed a short account of the solar system* [. . .] the sixth edition, with additions, by William Jones, London 1812.

In the preface to this work, Jones notes that the tellurium part follows the principles of James Ferguson's construction. He particularly recommends the instrument for its portability, cheapness and usefulness in schools, an application amply illustrated by the inscription on the present example.

75 ENGLISH ORRERY, *c.1820–30*

Movement of brass and steel; mahogany base covered with printed paper, coloured and varnished; the rim of the board painted red. Signed 'Newton *Chancery Lane*'. Diameter of base 218mm.

Circular base covered with paper printed with sun emblem, stars, and carrying a zodiacal calendar. Tellurium movement only, similar in design and operation to those of the New Portable Orreries.

76 ENGLISH ORRERY, *c.1830*

Movement of brass; mahogany base covered with printed paper, varnished; gilt wooden sphere for the sun and ivory spheres for the planets; silvered moon dial; turned ivory handle; rim of base painted red. Signed 'Published by [J. Newt]on 66 Chancery Lane & 3 F[leet S]treet, Temple Bar, London'. Diameter 327mm.

77 ENGLISH LEVER WATCH, *c.1795–1800*

Gilded brass case; enamel dial. Signed 'Geo: Margetts London No 1128'. Diameter 57mm.

The three dials of the watch show respectively hours, minutes and seconds. In the centre of each is a further dial which revolves in an anti-clockwise direction to give a direct reading of sidereal and mean time. This is achieved by duplicating the motion work beneath the dial and gearing it together in the ratio 341/56=6·0893.

The watch has a three-arm compensated balance wheel and is fitted with the only known example of Margetts' own form of lever escapement, with adjustable banking screws.
See Daniels, pp.356–7; Hope-Jones, pp.26–7; Turner, A. J., p.313.
Loaned by David R. Schwartz, Esq.

78 FRENCH CHRONOMETER WATCH, *1814*

Silver case with engine-turned silver dial. Signed 'Breguet no. 2894'. Diameter 69mm. Originally sold for 2,500 francs.

The dial with centre seconds hand and subsidiary dials for mean time (above) sidereal time on the left with calendar for the days of the month on the right.

The sidereal to solar ratio is derived from a complex train of gears behind the dial. The ratio of 1:1·0023768 is correct to the sixth decimal digit and within 10 seconds a year.
From a private collection. [SGW]

79 LE COUR ANNUELLE DU SOLEIL PAR TOUTE LA TERRE

pour servir à l'intelligence de la quadrature solaire. Divisé en deux tomes. *?Late eighteenth century*. Ms on paper, 280 × 315mm.

Contemporary mottled calf, gold stamped spine entitled 'Le cour annuelle du soleil' and signed 'Boüer' (bottom of spine), marbled end papers. Paginated vol.1, 1–230; vol.2, 1–187; ff.232 (221–32 blank).

A clearly written ms in a central frame of two rules, with 223 water-coloured diagrams (some folding); one 'Boussole des Ventes', with rotatable volvelle.

Separate title page to second volume: 'La Gnomonique / Universelle / la noble science de tracer / les cadrans solaires / sur toutes sortes de surfaces / tant staber que mobiler'.

A detailed treatment of the apparent motions of the sun in relation to the earth, and a comprehensive treatise on sundials in book two.

A pencil note in the front reads 'Francois Bedos de Celles Benedictin de l'academie de Bordeaux de la congregation de St. Maur'. In front of this a different hand has added the word 'par', but it has not been possible to substantiate this attribution.
Loaned by M. Nicolas Landau.

80 FRENCH PLANETARIUM, *c.1820*

Wood and brass; printed paper, coloured and varnished. Stand painted black with gilt floral decoration on the edges; the rims painted red. Signed on the globe 'G[LO]BE T[ERRESTRE] FOR[TIN] . . . PA[RIS]'. Diameter 500mm.

Turned base and column which contains the mechanism, actuated by rotating a turned ivory handle (a later replacement). The planetary arms are attached to a central wooden column by brass collars. Gilt globe representing the sun, around which rotates the earth, the moon and the planets out to Saturn. Each planet, except the earth, which is represented by a globe, is shown by a printed paper emblem. The whole is surrounded by an octagonal ring overlaid with a printed paper carrying a zodiacal calendar with pictorial representations of the signs of the zodiac.

81 FRENCH MANTEL CLOCK, *c.1780*

Porcelain; movement of brass and steel. Signed 'Schmit à Paris'. Overall height 483mm.

Striking movement contained in a Wedgwood blue case flanked by a white biscuit porcelain female figure (?Urania), holding a pair of dividers against a globe. The frieze surrounding the rectangular base is painted *en grisaille* and is from the factory of the Duc d'Angoulême. John Nicolas Schmit (*fl.*1781–1789) made a fine clock now in the Palace of Compiègne.

[SGW]

82 FRENCH PLANETARIUM CLOCK, *c.1810*

Movement of circular brass plates supported by brass pillars; marble base; glass dome painted with the months and signs of the zodiac. Signed 'LePaute de Belle Fontaine, Elementa suis propus armis victa' (which may be freely translated: LePaute of Belle Fontaine mastered the principles by his own equipment). Overall height (including dome) 620mm.

The planetarium with ivory spheres representing the planets and a brass star representing the sun, displays the revolutions of Mercury, Venus, Earth and Moon, Mars, Jupiter and Saturn. Uranus, discovered in 1781, has not been incorporated and Saturn only manually operable, presumably owing to the lengthy durations of their sidereal periods.

The planetarium gearing comprises two columns, one of four wheels and one pinion, the other of five wheels. The driving column revolves in 365 days, the arms of the planets being attached to the wheels on the second column by means of concentric hollow arbors. The gearing and period of revolution for each planet are as follows:

Mercury	365 × 26/108 = 87 days, 20 hours, 52 minutes
Venus	365 × 48/78 = 224 days, 14 hours, 45 minutes
Earth	365 × 60/60 = 365 days
Mars	365 × 75/40 = 684 days, 9 hours
Jupiter	365 × 95/8 = 4,334 days, 9 hours

The movement has a going period of approximately two and a half weeks, and strikes the hour and half hour on a bell. There is a dead-beat escapement with gridiron pendulum.

Jaques Joseph LePaute de Bellefontaine, Paris (*c.*1775–1830), in common with other members of this well-known French clockmaking family, made several very fine and unusual clocks including a twelve-month timepiece with 'equation of time' mechanism at Windsor Castle, and an astronomical 'pendule à gaine' at Waddesdon Manor. [SGW]

83 FRENCH MECHANICAL PLANETARIUM CLOCK, *c.1800*

Movement of brass and steel; cut crystals on brass arms for the planets; gilded brass armillary sphere; horizontal dial set with enamel plaques. Signed 'Invenit Thouverez à Paris Année 1797'. Overall height 598mm.

The movement has an unusual form of duplex escapement with a plain brass balance wheel. The planetarium portrays the relative periods of revolution of Mercury, Venus, the Earth and Moon, Mars, Jupiter and Saturn around the Sun. The earth rotates on its axis and the orbit of the moon is also represented.

The drive for the planetarium is transmitted from the great wheel of seventy teeth gearing with a wheel of eighteen teeth, the vertical arbor of which carries a wheel of twenty-four teeth connected to the planetarium train. It is then transmitted via an intermediate train to an arbor carrying five wheels all revolving once in 365 days. This intermediate train is geared as follows:
$24/72 \times 16/80 \times 8/72 \times 12/96$
The gearing for the planets is then as follows:

Venus	64/40 = sidereal period of 228·125 days
Earth	45/45 = sidereal period of 365·000 days
Mars	32/60 = sidereal period of 684·375 days
Jupiter	8/96 = sidereal period of 12·000 years
Saturn	4/118 = sidereal period of 29·500 years

Mercury is taken from the above-mentioned intermediate train, the gearing being $24/72 \times 8/64 \times 8/88 = 88$ days.

The arms for Mercury and Venus have been wrongly engraved, Mercury bearing the letter 'V' and Venus the letter 'M'.

The rotation of the earth is effected via three wheels mounted on its arm driven from the intermediate train and transmitted by one of the concentric hollow arbors with a wheel of eighteen teeth revolving once in six hours. The gearing is as follows: $18/36 \times 36/72$ ($\times 6$ hours $=$ 24 hours). The period of lunation represented is approximately twenty-four days.

The armillary sphere is engraved on the inside of the equinoctal ring with the months and the signs of the zodiac.

The maker Thouverez, or Touverez, or Thouverot is recorded in Baillie as working in the late eighteenth century. [SGW]

84 FRENCH SKELETON CALENDAR CLOCK, *c.1791*

Movement of brass and steel; marble base covered by a glass dome. Signed 'Thouverez HGER de Mr d'Orleans' and lower down 'Inventor Fecit Thouverez'.

The upper calendar aperture reveals a very unusual disc of parchment with a description of fifteen significant dates during the French Revolution. [SGW]
Loaned by Major Anthony Heathcote.

85 TRAITE DE MECANIQUE CELESTE

By P. S. Laplace. Five vols, Paris 1778–1825.

With Laplace's work, the mechanistic theory of the universe was given its fullest expression.

86 NOTIONS ELEMENTAIRE D'ASTRONOMIE

pour servir d'introduction à l'étude de la géographie. *Early nineteenth century.* Ms on paper, 210 × 298mm.

P.150, with one folding diagram and 25ff. blank and unnumbered.

An attractively written compilation of elementary astronomical and geographical information set out in the form of a dialogue. On p.7 (note 3) the writer states that Copernican armillary

spheres are still very rare, and he therefore prefers to explain the celestial movements according to the Ptolemaic system. For expository purposes, the two systems are of course equivalent, a fact which helps explain the survival of Ptolemaic spheres into the nineteenth century.

87 FRENCH PLANETARIUM, *c.1839 with alterations 1854*

Movement of brass and steel; ivory spheres for planets; globe for earth of engraved and coloured gores on a wood core; cabinet of mahogany. Globe signed 'DELAMARCHE PARIS Rue du Jardinet, 12, 1839'; movement marked '5 REPARE PAR PAGET H^{R} 1854'. Overall height 2,960mm.

Sexagonal cabinet providing a cupboard and containing at the top the clockwork movement which when wound up and set going, runs for thirty minutes. Around the large brass sphere representing the sun revolve the planets

Mercury
Venus
Earth with Moon
Mars
Jupiter with four satellites
Saturn with eight satellites
Uranus with eight satellites

Between Mars and Jupiter, four asteroids are shown. These are presumably Ceres, Pallas, Juno, and Vesta. A fifth Astraea was discovered in 1845, but is not shown. Carried on the same central shaft is a horizon ring engraved with a zodiac calendar. A pointer carried on the Earth/Moon arm is read against this scale. Saturn's eighth satellite was discovered in 1845. Uranus is only known to have five satellites, although in 1798, Herschel published a paper in which he claimed that it had six. An explanation of the eight shown here may be that when the third and fourth satellites were recognised in 1851, Paget's 'réparation' in 1854 included adding these to the erroneous six of Herschel.

Clockmakers by the name of Paget are known at Morez, Béziers, Lyons and Paris during this period.

88 FRENCH ORRERY CLOCK, *c.1820*

Movement of brass and steel; silvered brass dial; zodiac ring of patinated bronze; central column of blued and engine-turned metal; case of cast and gilded bronze, finely engraved and engine-turned. Signed 'RAINGO A PARIS'. Overall height 762mm; diameter of base 381mm.

The movement with dead beat escapement and temperature compensated gridiron pendulum suspended from immediately behind the dial, strikes the hours on a bell. A double ended hand on the vertical dial indicates the day of the week with one hand and the planetary deity with the other (symbol for the planet from which the day of the week was derived).

The orrery portrays the motions of the earth and moon in rotation around the sun and displays the following information:

1. The days of the month and month of the year.
2. The position of the sun in the ecliptic.
3. The bissextile (leap year cycle).
4. The age and phase of the moon.
5. The sidereal period of the moon.
6. The approximate declination of the sun.
7. The approximate lines of sunrise and sunset in the northern hemisphere.

The orrery carriage revolves anti-clockwise around a central arbor underneath the sun, and a steel pointer at one end indicates the date and position of the sun in the ecliptic against the two horizontal dials on top of the pediment. Above this pointer is the dial for the bissextile containing divisions for the leap or ordinary year. Through an aperture in the dial, the orrery movement is wound once every four years. Therefore this dial not only indicates the leap year for adjustment in February but also the time for re-winding.

The inclined earth rotates on its axis in twenty-four hours, within a metal ring attached to

the sun representing the eliptic. Two curved arms represent the lines of sunrise and sunset, and above, the time on a twenty-four-hour dial is shown.

The moon although not kept in its proper plane, rotates on its axis simulating the phases, and orbits the earth. A pointer on the dial below indicates its age and the quarter points of the lunation.

The entire orrery mechanism may be disconnected from the movement of the clock by loosening a set screw. The orrery may then be hand-operated by placing a key over the protruding arbor at the right-hand side.

The drive for the yearly revolution of the orrery carriage is obtained from the intermediate pinion of the going train, extended through the back plate, to a train of wheels geared to the central arbor which is sunk into an engine-turned blued metal cylinder.

The name Raingo is always associated with fine orrery clocks similar to this one, although the firm produced many other types of domestic clocks in the nineteenth century. Of this type, nine were listed by Colonel Quill (*Horological journal*, December 1960), of which two subsequently disappeared. A tenth was located by Professor Hans von Bertele (*Antiquarian horology*, March 1963), and signed 'Raingo à Gand'. There is also one in the private collection of Grassy, the jewellers in Madrid, and another (unsigned) in the Royal Palace, Madrid, which do not appear to have been listed before. [SGW]

89 ENGLISH REGULATOR, *c.1910*

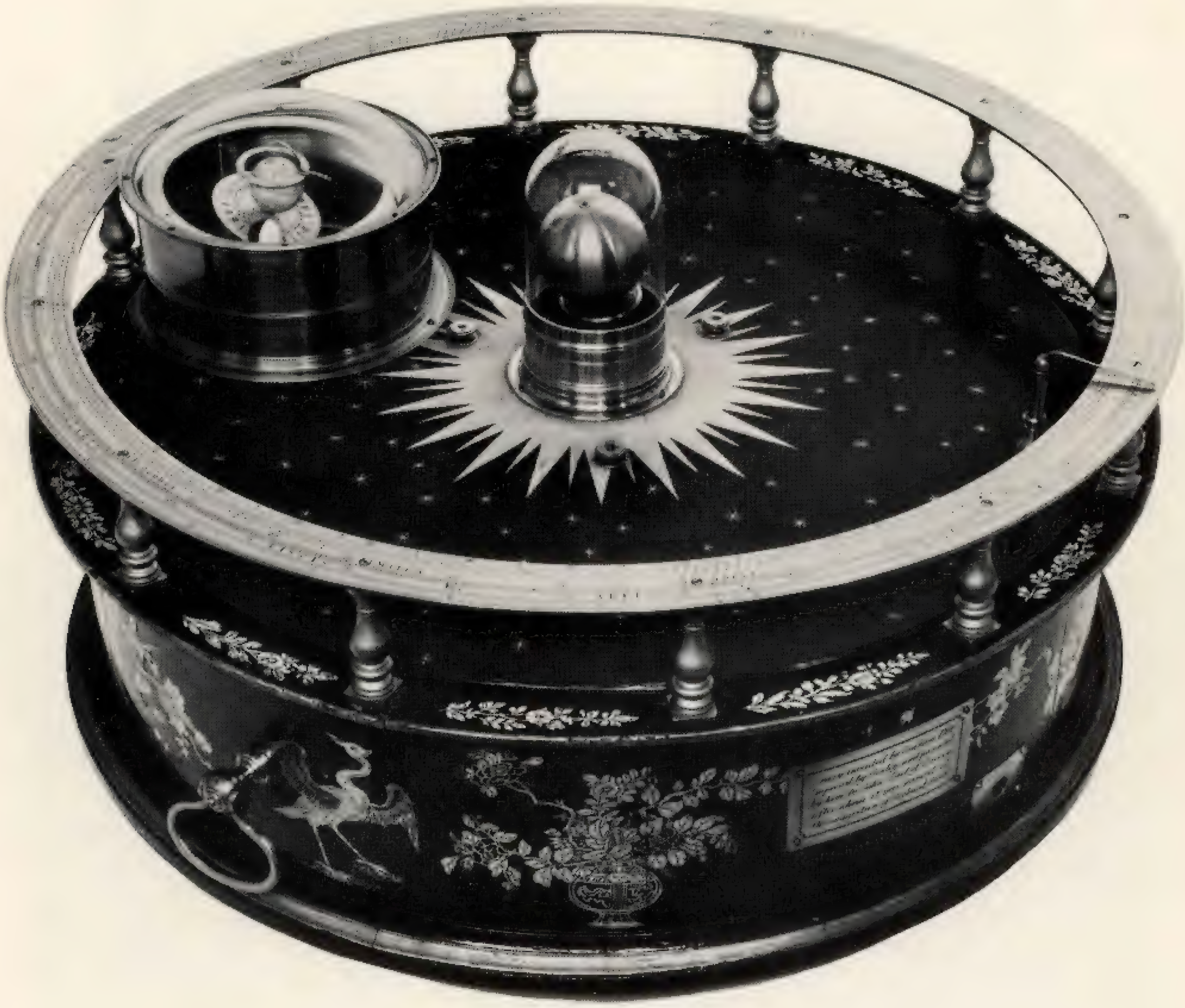
Movement of brass and steel; silver dial; case of mahogany. Signed 'T. Cooke & Sons of York and London'. Height 2000mm.

The dial with centre minute hand and subsidiary dials above for the sidereal seconds, lower left for the sidereal hours and minutes and lower right for mean time hours, minutes and seconds. The movement with four pillars contains a three wheel train for sidereal time and complex intermediate train for converting to mean solar time. The pendulum which is separately suspended has a zinc and steel rod with silver plated cylindrical bob. The sidereal to solar ratio is approximately 1:1·002,737,909. The case also contains a thermometer and barometer.

Clocks giving both sidereal and solar time by means of an intermediate conversion train are rare. This clock was made for Admiral C. A. Fontaine, for his private observatory in which he plotted the time digression caused by the nutation of the axis of the earth. [SGW]

39. Medal of Sir Isaac Newton, 1731

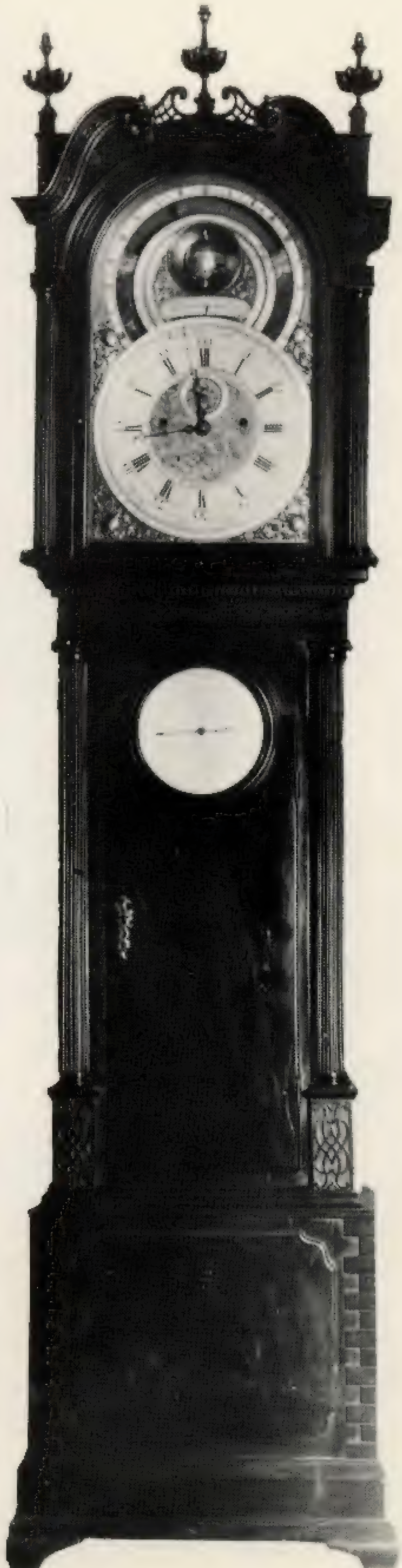
44. English orrery, *c.*1710



45. English orrery, *c.*1710–12

47. English grand orrery, *c.*1740–50

◀ 58. English long case clock, *c.*1750 ▼



59. English timepiece, *c.*1770

57. English astronomical bracket clock, *c.*1735

63. English planetarium, *c.*1800

60. English long case clock with celestial planisphere, *c.*1790

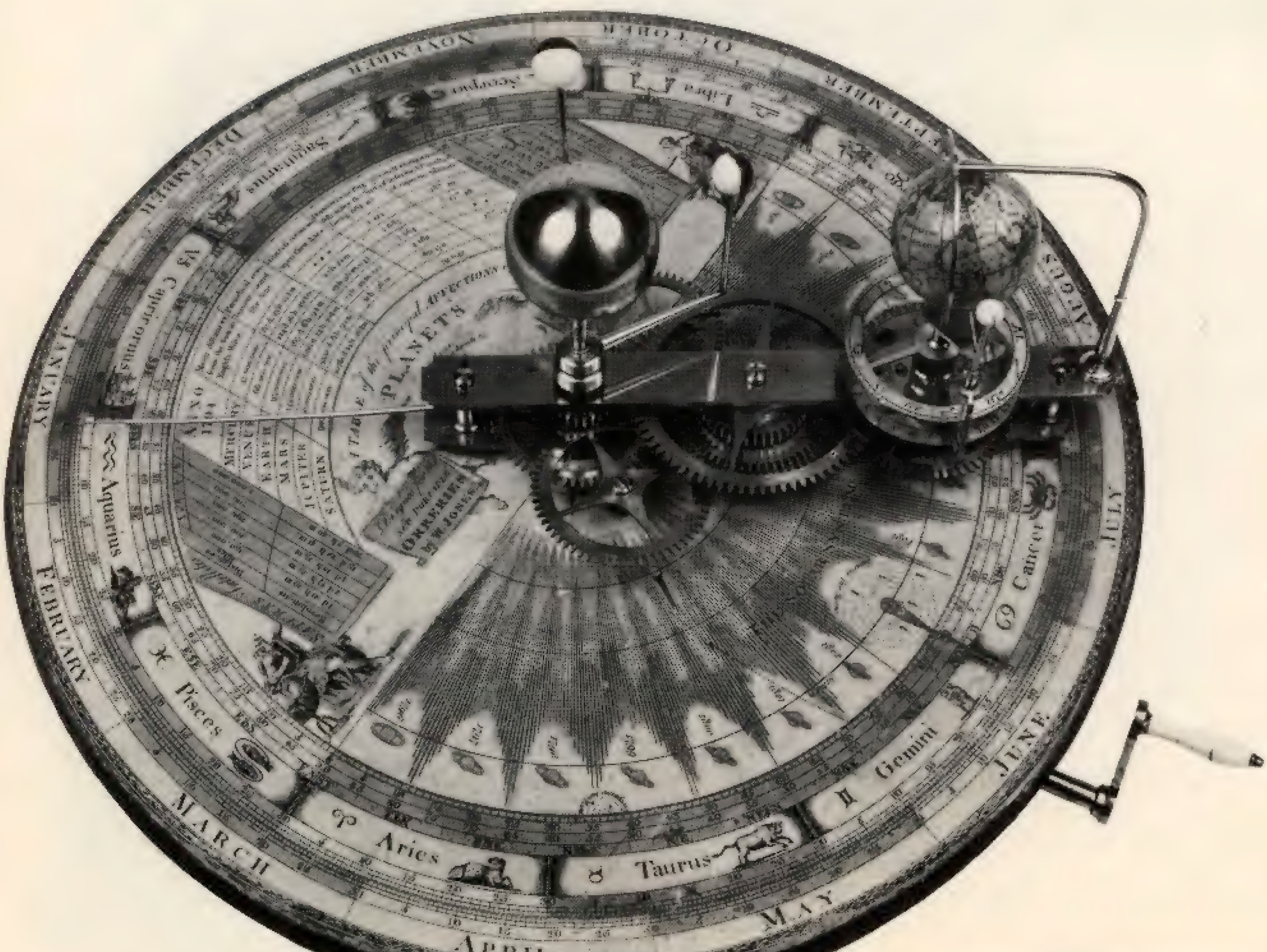
66. French Ptolemaic armillary sphere, *c.*1780

67. French Copernican armillary sphere, *c.*1800

69. Electric orrery, *c.*1780

68. French mantel clock, *c.*1760

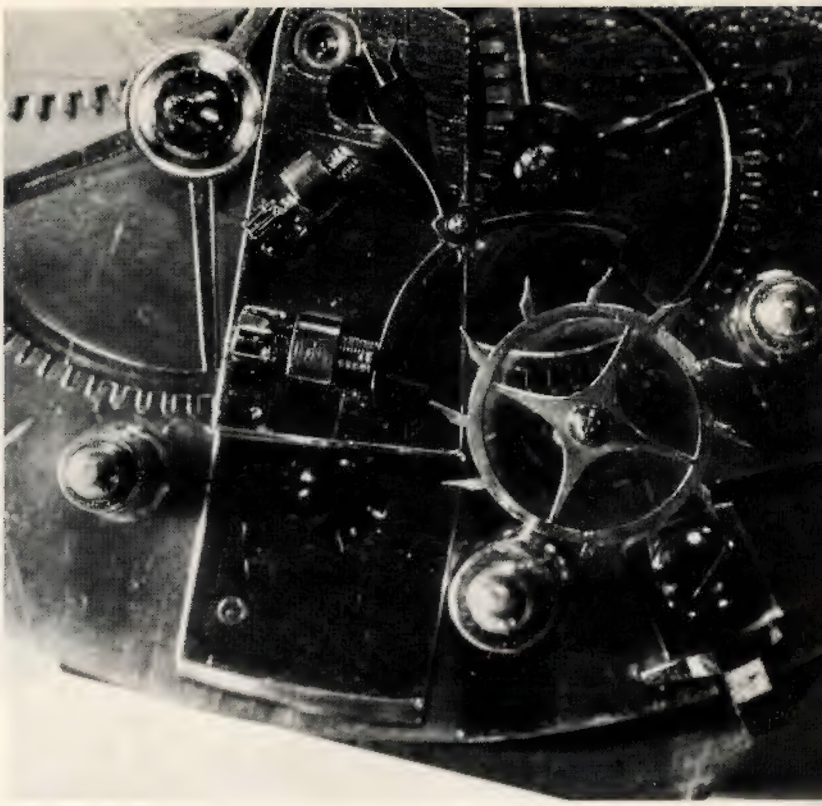
71. Copernican armillary sphere, nineteenth century



73. English orrery, *c.*1810–20

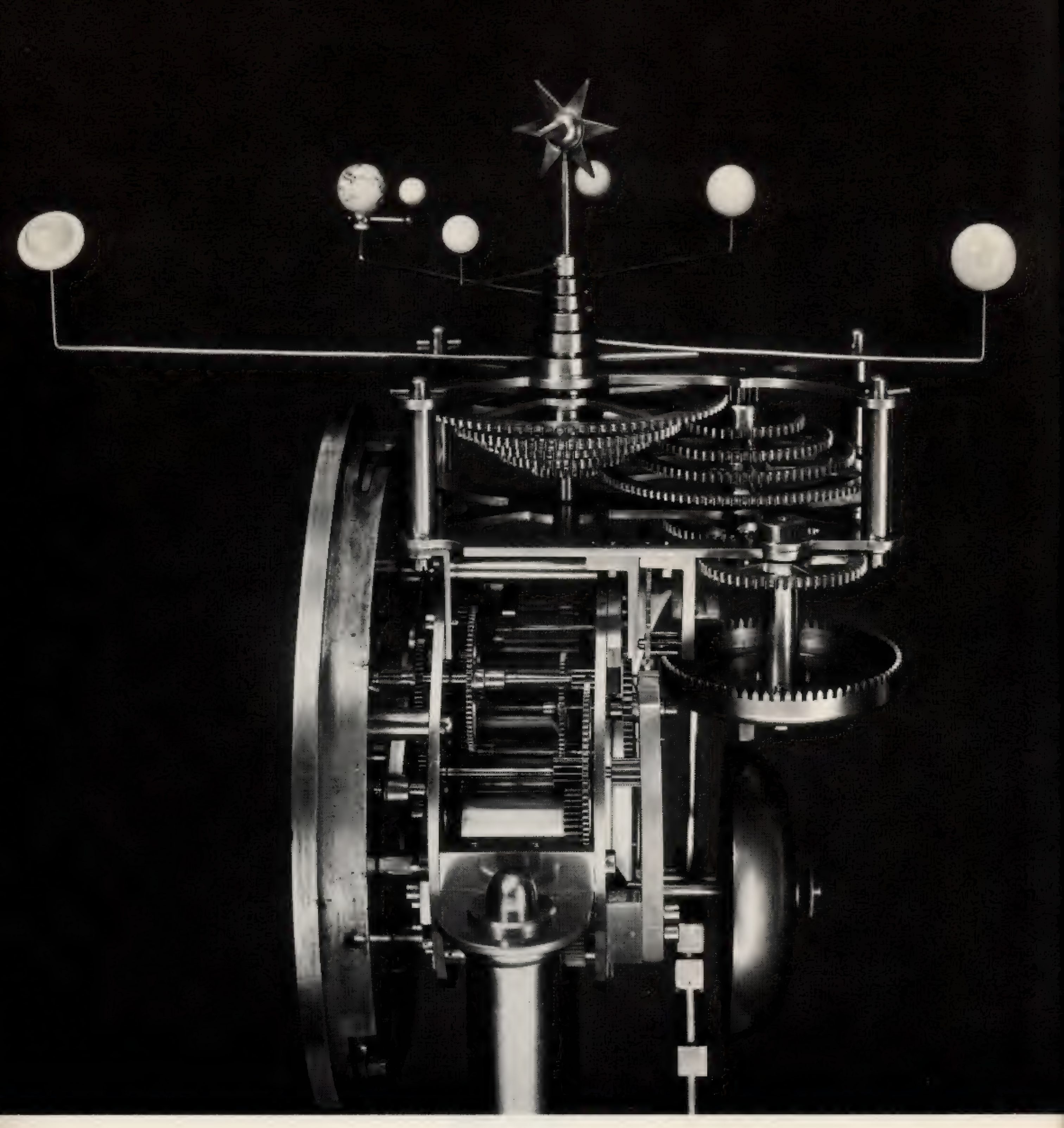
74. English orrery, *c.*1812

77. English lever watch, *c.*1795–1800 ▶



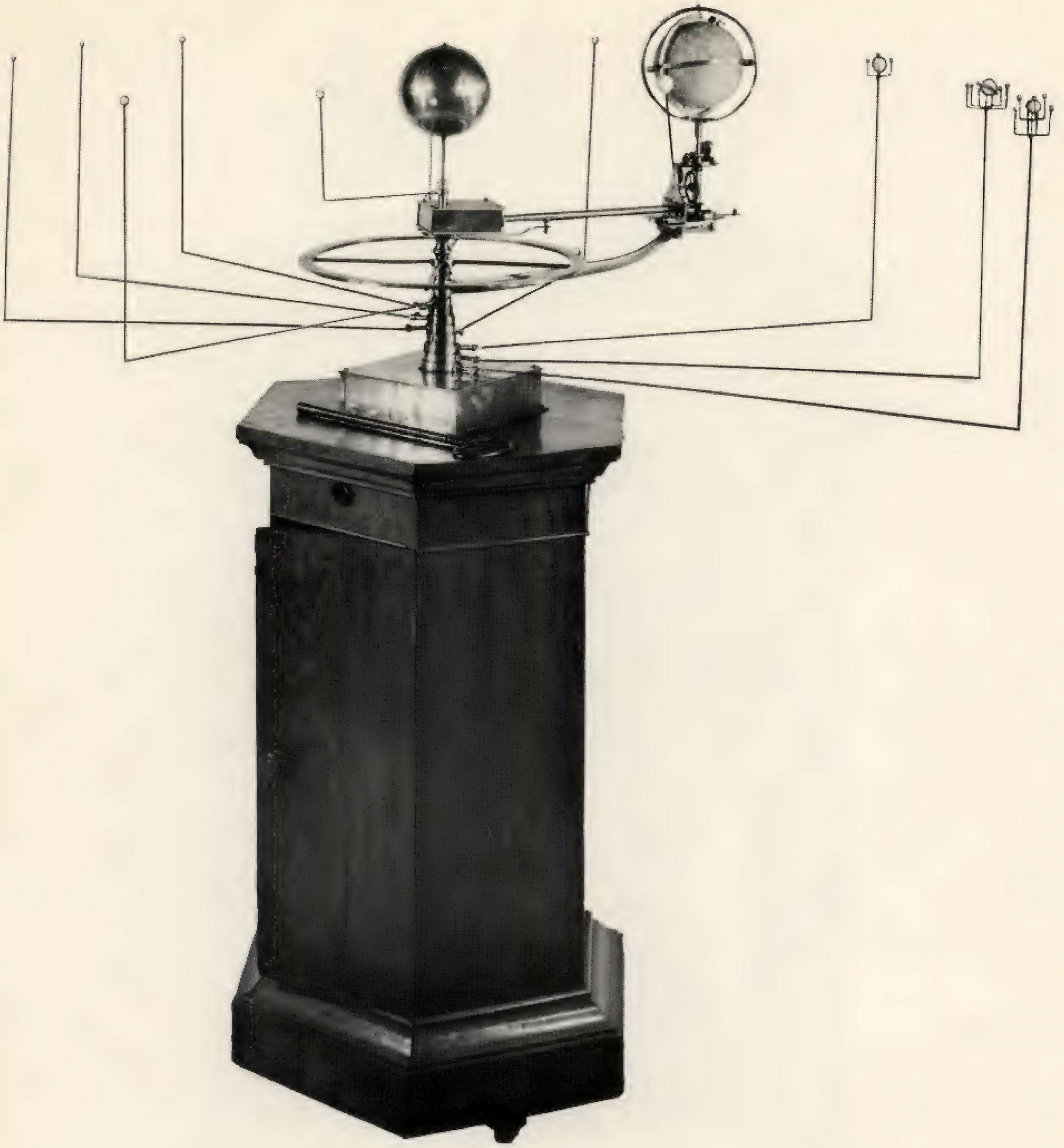
78. French chronometer watch, 1814

81. French mantel clock, *c.*1780



◀ 82. French planetarium clock, *c.*1810 ▲

83. French mechanical planetarium clock, *c.*



87. French planetarium, *c.*1839 with alterations 1854

88. French orrery clock, *c.*1820

Notes

1. Genesis I:1, 6, 8, 14–18. Authorised version.
2. Job XXXVIII:31–33. Authorised version.
3. Ferguson (2), p.6.
4. Cohen & Drabkin, p.97.
5. *De Republica* I:14; Hardingham, p.25.
6. Cited from *Collectionum mathematicarum*, ed. Federicus Commandinus, Urbino 1588, in Stevenson, p.17. Compare also the comments of Proclus Diadochus, Cohen & Drabkin, p.5.
7. Hardingham, pp.25–27. For other comments on Archimedes' sphere by ancient writers, see Cohen & Drabkin, pp.142–43, and Price (2), pp.89–90.
8. Cohen & Drabkin, p.143.
9. Price (2), pp.86–88.
10. For this problem see Dicks, pp.195–207. On astrolabe projections in general see Maddison (2). For use and history of the instrument, Gunther, Hartner, Maddison (1) and Michel (1).
11. So named from the fact that it displayed the successive risings of star constellations above the Eastern horizon throughout the night.
12. Drachmann.
13. Price (2), p.94, and Price (3).
14. Millas-Vallicrosa, p.132.
15. Needham, Wang Ling & Price, pp.74–80.
16. Price (2), p.98.
17. IC no. 5, Mayer p.59, now in the Museum of the History of Science, Oxford.
18. For history of equatoria see Price (1), pp.119–33.
19. Beckmann, vol.i, pp.349–50, citing Trithemius.
20. Lattin (1), p.184, 15 January 989.
21. *Ibid;* Price (2), p.102.
22. Millas-Vallicrosa; for a briefer account but in a broader context, see Haskins.
23. See no. 6, above.
24. Thorndike (2), pp.180, 230. Cp. Thorndike (1).
25. Price (2), p.100; Bedini & Maddison, pp.9–10.
26. Cited from Price (2), p.109.
27. Bedini & Maddison, pp.5–8. For the albion see Price (1), pp.126–28.
28. Cited from Bedini & Maddison, p.7
29. Cited from Bedini & Maddison, p.20. For the *astrarium* see *ibid*, pp.14–17; Lloyd (2), pp.9–24.
30. Froissart, *Li Orloge Amoureus*, 11, 6–11, translation from Drummond Robertson, p.55.
31. Cited from Cipolla, p.42.
32. Bedini & Maddison, p.50.
33. *Ibid*, p.5.
34. *Ciel*, 40:v.
35. For examples see Cipolla, p.122.
36. *Paradiso*, x:139–141; Temple Classics translation.
37. Bizet, pp.55–71; Spencer, p.278.
38. Spencer, p.282, translated by C. B. Drover.
39. Suso, cited from Spencer, pp.282–83.
40. Bright, p.45.
41. Du Bartas, p.75.
42. *Ibid*, p.72.
43. Kuhn, ch.4, especially pp.124–25.
44. Powell, p.24.
45. *Ibid*, pp.25–26.
46. *Ibid*, pp.19–20. For Drebbel's device see also Dircks and Michel (2).
47. Gonçalez, *Consideracion I*, trans. Hilary Smith.
48. Epitaph on the tomb of Lady Dodderidge, in Exeter Cathedral, died 1 March 1614.
49. Lee, p.36.
50. Suckling, p.64.
51. Glanvill, p.51. For a fuller discussion of Cartesian use of the clock metaphor, see Laudans.
52. Cited by Laudans from the Principles of Philosophy, *Oeuvres*, ix, p.322.
53. Power, p.183, following Sir Thomas Browne, *Religio Medici* (1643), Book 1, section 13.
54. *Ibid*, pp.192–93.
55. Gunther, vol.vi, p.159.
56. Bedini & Maddison, p.25.
57. *Ibid*, p.26.
58. For de' Dondi mss at Cracow, see *ibid*, p.27; for Hans Dorn's globe see Ameisenova.
59. Bedini & Maddison, pp.37–40.
60. Lloyd (3), pp.46–57. Bound into Wilhelm IV's copy of Apian is a 17 page ms containing his and Andreas Schoener's calculations for the clock.
61. Lattin (2), p.99.
62. Hillard & Poulle, pp.315–16.
63. *Ibid*, p.318.
64. For a survey see Bertele (1).
65. *Op. cit*, p.315.
66. *Op. cit*, pp.8–10.
67. Evans, p.245.
68. *Ibid*, p.188.
69. Lattin (2), pp.109–10.
70. North.
71. Bertele (2).
72. Horsky, pp.27–29.
73. Lattin (2), pp.153–56.
74. Derham, ch.II, section 5.
75. *Ibid*, p.91.
76. See Lloyd (2), pp.88–95 and Lloyd (1).
77. These models are now in the Museum of the History of Science, Oxford.
78. *The Englishman*, 12, 27–29 October 1713.
79. Hall, p.120.
80. See Alexander. For accounts of Newton's system, see Hall, ch.x and xi; Kuhn, pp.254–65.
81. Hall, p.303.
82. *Principia*.
83. Ferguson (1).
84. Millburn, p.209.
85. Lattin (2), p.169; Turner, G., pp.218–19.
86. Martin.
87. Lattin (2), p.170; for descriptions of his various instruments see his own works and Henderson.
88. For the New Portable Orrery see Jones (1), for prices Jones (2), p.8.
89. Motte, signature A4r.
90. *Tusculan Disputation I*, xxv.
91. Bridgewater, p.52.
92. Pope, vi, p.317.
93. *Ibid* iii, pp.56–57, 59–60.
94. Cited from Donaldson who discusses other aspects of the metaphor in 18th century novels.
95. Hall, p.298.
96. Cited from Buchdahl, p.7.
97. Lithographed watch paper of F. E. Rutherford, Hawick, now in the Museum of the History of Science, Oxford. See Maddison & Turner, W302. The lines seem to have appeared first in the Scots Magazine, October 1747, being attributed to John Byron.

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